6. Scofield Reservoir Phase I, 314 Clean Lakes Study, 1980 - 1982, Richard L. Denton, Project Officer; Myron I Cox, Water Quality Specialist; Lavere B Merritt, Ph. D., Brigham Young University in cooperation with the Utah Department of Health, Division of Environmental Health, Bureau of Water Pollution Control, and Brigham Young University

Appendix F October 1, 2002 Internal Correspondence, Expected Water Inflow Rates

Appendix G Petersen Hydrologic Report

Investigation of Fault-related Groundwater Inflows at the Skyline Mine
27 October 2002

Table of Contents provided at the front of the report in the appendix

Appendix H HCI Status of Ground Water Flow Modeling for Skyline Mine

Prepared by HCI in May 2003 as interim report for ground water model of the Skyline Mine permit and Electric Lake area.

Appendix I Petersen Hydrologic Electric Lake Dye Letter Report

Letter report prepared by Petersen Hydrologic in June 2003 discussing the results of the collection and analysis of dye tracing packets placed in ground and surface waters in and around the Skyline Mine permit area in response to PacifiCorp's Electric Lake dye placement activities.

Appendix J HCI Ground Water Flow Modeling of Skyline Mine and Surrounding Area

A ground water model of the Star Point Sandstone aquifer that discharges to Skyline Mine was completed in October 2003 by HCI of Lakewood, CO. The model incorporates all of the available well, surface flow, and ground water discharge data available and germane to the model area. The model also was used to predict the future volume of ground water inflows to the mine using the most current mine plan.

In March and April of 2003, PacifiCorp began drilling a third well, JC-3, at the James Canyon well site to intercept the mine workings in the 10 Left area. The well was completed in July 2003 and began pumping water on July 27, 2003. The purpose of this well is to remove water from the mine as close as possible to its inflow point in 10 Left and discharge it to Electric Lake. The JC-3 well has a down hole casing diameter of 24-inch and is screened through the mine works. PacifiCorp, with Skyline Mines' aid, obtained a UPDES discharge permit to allow discharge of mine water to the lake.
It will be outfitted with a variable frequency drive to allow lower volumes to be pumped.

Water discharged from JC-1 and JC-3 is piped from the James Canyon well site to Electric Lake through a buried 16-inch HDPE pipe. When initially constructed in September 2001, the end of the 16-inch pipe was submerged approximately 8 feet below the water level of Electric Lake. A 90-degree elbow was attached to the pipe at approximately 45 degrees above horizontal to avoid disturbing sediments on the bottom of the lake. However, continuing drought conditions in 2001 and 2002 resulted in the lake water level dropping below the end of the discharge pipe. A small area of lake sediments were washed away and the water discharged onto large rocks and cobbles on the surface of the pre-lake ground surface, in effect creating its own rip-rapped energy dissipation area.

The James Canyon wells are considered to be mine dewatering wells. A UPDES permit, however, is only required for the discharge of JC-3 since this is the only water coming directly from the mine works.JC-1 and JC-2 are completed in the Star Point Formation and do not intercept the mine works.

A geologic cross section through wells/drill holes W2-1, JC-1, JC-2, W79-35-1, 75-26-3, 74-26-2, and 79-22-1 has been provided as Drawing PHC A-4. The location of the mined coal seams, faults, apparent dip of the beds along the cross section, and a site index map are provided. Also, the location of the mine in-flows of ground water have been projected horizontally to the cross sections. The location of selected springs have been illustrated on the cross section. The elevation of Electric Lake and the dates these measurements were taken are illustrated on the wells with ground water levels.

Effects of Intercepted Water within the Mine on the Local Ground Water Systems

Skyline Mine has continued to monitor ground and surface water flows at all of the Mining and Reclamation Plan (M&RP) required water monitoring sites. No discernable impacts to surface springs or surface waters from the increased ground water inflows to the mine has been observed to date. Specifically, quarterly flow monitoring of seeps and springs in the Huntington Creek drainage area indicates the significant inflows of ground water to the mine and pumping of the wells in James Canyon has not had an observable effect on ground water discharges in these areas. Furthermore, historical spring and seep data do not indicate a reduction in spring, seep and stream flows related to mining.

Included in this document in Appendix A are several graphs generated from measurements of springs and stream flows and well water levels located throughout the Skyline Mine permit area. Each graph illustrates the discharge or water levels compared to the Palmer Hydrologic Drought Index (PHDI) for Region 5, which includes the mine area, from 1982 to May 2002. Data from the following springs, stream, and well monitoring locations have been graphed: springs S15-3, S22-11, S24-12, S26-13, S34-12, S35-8, S36-12, 2-413; stream monitoring point Burnout Creek F-5; and wells W2-1, W20-4-1, W20-4-2, W99-28-1, W99-21-1,W79-14-2A, W79-10-1, W79-35-1A, W79-35-1B, and W79-26-1. Also, a single graph illustrating the water levels in W79-35-1A, W79-35-1B, W2-1 and the PHDI is presented to compare the effects of mine dewatering on the three wells. Graphs of transducer data for wells W79-35-1A, W20-4-1, and W2-1, which are completed in the Starpoint Sandstone beneath the mine, are presented to illustrate in greater detail the recent draw down of the wells. These last three graphs can be found following the graphs containing the PHDI. Accompanying each spring, stream and well graph is a brief comparison of the discharge or water level and the PHDI. Table PHC A-2 contains a summary of the well completion and water level measurement data for the Skyline Mine water monitoring wells.

Spring discharges, as shown in the graphs, aptly illustrate that almost all discharges from the shallow ground water aquifers are controlled by the fluctuations in yearly precipitation or drought cycles as illustrated by the PHDI. A notable exception is spring S24-12. The graph appears to illustrate a significant drop in spring discharge beginning in 1989. However, as presented in the text attached to the graph, the apparent change in discharge is related to a minor shift in the location of the discharge and not in the total volume of water released from the aquifer in the spring area.

Several springs, for which graphs of flow data have been provided, have been undermined since mining began at the Skyline Mine in 1982 (Drawing PHC A-3). As stated above, the fluctuations in spring discharge are easily related to fluctuations in climatic conditions and not mining activity. The relationship between spring discharge and mining activity was studied in great detail as part of an EIS performed by the Manti-La Sal National Forest for the Flat Canyon Tract located west of the existing mine leases. The study was performed by Norwest in the summer of 2000. The water monitoring data compiled by the mine since mining activities began in 1982 were studied for any effects on surface and shallow ground water discharge. The conclusion of the study was there is very little evidence that undermining or mining within the vicinity of the springs in the Skyline Mine area has resulted in the diminishment of discharges from the springs. A copy of the Norwest study has been provided in Appendix B of this document.

A comparison of the water chemistry of five springs, the JC-1 well, and three in-mine sample locations has been provided in Appendix A. Stiff Diagrams are provided for springs S22-11, S26-13, S34-12, S35-8, 2-413 and the James Canyon well JC-1. Stiff Diagrams are also provided for water samples obtained from the 10 Left Entry 3 Borehole, Fault Crossing at the West Submains (now referred to as the East Submains), and the 9 Left Horizontal Borehole. A notable difference between the spring water and the James Canyon and in-mine waters is the amount of magnesium in the water. Significantly greater amounts of magnesium are found in the mine and well water than in the spring waters.

Notable differences in the chemistry of intercepted ground water in the mine and the waters found in Electric Lake were found by Hydrologic Consultants, Inc. (HCI) of Lakewood, Colorado. HCI was contracted by Skyline Mine in August 2001 to aid in determining the source of the ground water entering the mine and to help the mine determine how long the inflows could be anticipated to continue, HCI initially submitted a brief report to Skyline in November 2001 regarding where they thought the water coming into the mine may be originating. Subsequent to their initial report, more data were gathered concerning water chemistries, monitoring well data, and water age dating information (Tritium and Carbon 14). A copy of their second report is included as Appendix C. Briefly, the conclusion of their report (page 12) was that chemical and isotopic differences between water entering the mine and Electric Lake suggested strongly that no direct conduit exists between the mine and the lake.

Petersen prepared a report titled "Investigation of Fault-related Groundwaters Inflows at the Skyline Mine, 27 October 2002". This report is included as Appendix G to this document. This report expands upon the data presented and conclusions of the Petersen Report in Appendix A and the HCI report in Appendix C. Petersen evaluated the chemical composition of the in-mine and surface waters. He concluded that water in the 10 Left area is significantly dissimilar to surface waters and surface waters cannot evolve chemically into the 10 Left waters in the hydrogeologic environment of the mine (Petersen, October 2002, Appendix G, Section 6.5, p. 17). Following is excerpt from his report that details the differences between surface and in-mine waters:

> "Likewise, solute and isotopic data indicate the Electric Lake cannot be a major source of the fault-related groundwater that is flowing into the Skyline Mine. Based on the solute compositions of Electric Lake water and water from the fracture system associated with

the aquifer in the mine area (HCI Figure 6, Appendix C and Petersen Figure 4 Appendix G, HCI Figure 19 Appendix J). The boundaries of the aquifer discharging ground water to the mine from the Star point is illustrated on Plate II of the HCI Ground Water Model (Appendix J).

Recharge to the Star Point Sandstone appears to be slow as evidenced by the continued draw down of the aquifer and the age of the in-mine water. Based on the HCI ground water model, the recharge area to the aquifer appears to be south of the mine in the northern portion of the Joe's Valley Graben system. The drawdown rate of 0.08 feet per day in W79-35-1A was calculated for the time period between April 17, 2002 and July 1, 2002 (6 feet of drawdown over 74 days) and suggests that the potentiometric head of the ground water in the area at the head of the 9 Left panel will be at or near the elevation of the coal seam (a drop of 85 feet) in approximately 1060 days. It is reasonable to assume that mine inflows will decrease as the head is removed from the aquifer. Quantifying the rate of decrease and times at which the flows will decrease is difficult at best. According to HCI's model, the flows to the mine should diminish to approximately 3,700 gpm by 2013, assuming a the mine remains in operation and no additional areas of the mine are flooded. The inflow rate could be diminished by flooding, and thus adding head to the inflows, the southwestern portion of the mine including the 11, 12Left A, and 12 Left B panels.

Skyline Mine continues to provide periodic updates to the holders of the water rights in the mine area of the results of the studies the mine is performing to determine the sources and impacts of the mine dewatering on the area ground water resources.

Effects on Surface Waters

Discharge from the Skyline Mine to Eccles Creek has steadily increased since January 1999 as discussed previously. The mine discharged water to Eccles Creek at a rate of approximately 9,500 to 10,500 gpm, with a portion of the water discharged coming from stored water in Mine #3 until August of 2003. After this date, the discharge from the mine to Eccles Creek dropped to about 3,000 gpm when discharge from Mine #3 was suspended and JC-3 went online and began pumping about 5,000 gpm to Electric Lake. Eccles Creek runs at near bank full conditions when the mine discharges at a rate of 9,000 gpm to 15,000 gpm. The channel has a fairly steep gradient, is well armored, often flows directly over bedrock, has few meanders, and has extensive vegetative growth on its banks (EarthFax, Appendix D). Several abandoned beaver dams have been or are in the process of being eroded. However, the rate of erosion is very slow and addition of sediments from the dams and ponds is slight.

Mud Creek has a much lower gradient than Eccles Creek and has increasing numbers of meanders as it approaches the town of Scofield. The channel banks and floors consist of fine grained sediment with minimal vegetative cover. At current discharge rates, the channel is not yet at bank full conditions and not subjected to significant erosion (EarthFax, Appendix D). Increased flow rates from the mine could impact this stream channel more significantly than the Eccles Creek channel if flows from the mine increase. However, Mud Creek has a significantly higher full carrying capacity than does Eccles Creek. EarthFax was contracted by Skyline to prepare and implement a work plan that involved locating several sites on both Mud and Eccles Creek where the stream channel morphology, vegetation, flow volume, and water chemistry would be monitored on a regular basis. The purpose of the monitoring is to determine what, if any, impacts may be occurring as Skyline Mine discharges large volumes of ground water to these creeks. The monitoring of these aspects of the Mud and Eccles Creeks will continue until at least one year after the mine discharge volume drops to or below pre-March 1999 discharge levels of approximately 350 gpm.

Scofield Reservoir was constructed to serve as flood control, storage for irrigation water, and a drinking water source for Price and the surrounding communities. It has a storage capacity of 73,600 acre feet of water. Assuming the mine continues to discharge at an average rate of approximately 10,000 gpm, this would add approximately 44 acre feet per day of water to the reservoir. This represent approximately 0.06% of the maximum daily storage capacity of the lake. Normally, Eccles Creek drainage contributes less than 1 acre foot per day of water during minimum baseline flow conditions.

The concentration of salts in the mine water discharged to Eccles Creek as measured by the Total Dissolved Solids (TDS) concentration was between 400 and 650 mg/l from July 2000 to June 2001. Between June of 2001 and February 2003, the average TDS concentration of the water discharged from the mine was less than 500 mg/l. Between March 2002 and September 2002, the TDS concentration in the mine discharge water was consistently less than 400 mg/l. Since September 2002, the TDS concentration has ranged between 425 mg/l and 625 mg/l. The increase in TDS since September 2002 is related to the discharge of additional stored Mine #3 water. The average concentration of TDS in Eccles Creek above the mine is slightly less than 300 mg/l with seasonal variations of concentrations between 165 and 435 mg/l. Skyline Mine is working with the Utah Division of Water Quality (DWQ) on methods to reduce the overall concentration of TDS in the mine discharge water. Discussions center around a new TDS discharge limit of 500 mg/l for mine water. This has not yet been approved. The mine is pursuing several potential projects to either reduce TDS concentration or mitigate its effect on the downstream water bodies. These potential projects include capturing more of the mine water underground at its source to eliminate TDS that enters the water as it passes through gob, and participating in salinity reduction programs in the Castle Valley area.

Total Suspended Solids (TSS) concentrations in the mine water discharged to Eccles Creek have typically been within the limits set by the mine's UPDES permit. Over the past 10 years, infrequent exceedances of the limit have occurred. These occurrences have become rare since 1999 with one exception. In August 2001, a release of coal fines to Eccles Creek was reported by the mine to DWQ and DOGM. No significant environmental damage occurred as a result of the release because of its short duration and minimal volume. Changes to the mine's water handling system were instigated to prevent future occurrences of this type of release.

No increase in nitrogen or phosphorous compounds above background level has been detected in the mine water discharged to Eccles Creek for several years. A brief study on the effects of mine discharge with regard to total phosphorous was performed by EarthFax in December 2001 as part of the Flat Canyon EIS. A copy of the study is included in Appendix D. The results of this preliminary study indicate that it is unlikely that mine water itself will contribute significant concentrations of total phosphorous to Scofield Reservoir. However, since the Scofield Reservoir is a drinking water source for Price, a top cold water fishery in the State, and has been listed as an impaired water body by the EPA, increases in total phosphorous released to the reservoir is of special concern. Several studies have been conducted since the mid 1970's by the Utah Division of Wildlife Resources, Utah Department of Environmental Quality, and the USGS to determine the sources of phosphorous pollution in the lake. Copies of several of these studies are included in Appendix E. Generally, the studies have identified two significant sources of phosphorous pollution - sediments entering the reservoir and runoff from lands carrying animal waste into the lake. A report written 1992 by Harry Lewis Judd of the Utah Division of Water Quality, Utah Department of Environmental Quality titled "Scofield Reservoir Restoration through Phosphorous Control" suggest that as much as 29% of the total phosphorous load in Scofield Reservoir is delivered by Mud Creek. He sites the poor conditions of stream banks in the lower sections of the creek south of the town of Scofield and the recreational and industrial activities that occur in the drainage as the source of much of the sediment that contains the phosphorous that is detrimental to the lake's water quality. The idea that sediments transported to the lake by its tributaries is a significant source of phosphorous is supported by previous studies.

Beginning in 2002, the total phosphorous concentration in the water discharged into Eccles Creek from the mine has been monitored. Orthophosphate concentrations have historically been monitored in the discharge water along with periodic monitoring for total phosphorous concentrations. A new monitoring plan to evaluate the effects of increased mine discharges on the stream channels of Mud and Eccles Creek was instigated in the summer of 2002. This study includes monitoring several locations on both creeks for changes in stream morphology and water chemistry. Two sites on Eccles and six sites on Mud Creek will be monitored for total flow, TDS, TSS, and total phosphorous. If significant increases in TDS, TSS, and total phosphorous or changes in stream morphology and/or plant communities are noted, the sources will be investigated. If they are related to Skyline Mine activities, remedial actions will be taken. These actions may consist of, but not limited to, armoring stream channel banks, planting of stream bank stabilizing vegetation, or redirection of some flows to the Huntington Creek drainage. Monitoring information is provided in the "Addendum to the Probable Hydrologic Consequences, July 2002, Appendix D and the work plan for monitoring is provided in Attachment 3 of Section 2.12. Future monitoring information will be provided in the Annual Report.

Total and dissolved iron concentrations in the water are typically below 1 mg/l, similar to background water concentrations. Nickel concentrations have reached as high as 40 μg/l. This concentration is well below the UPDES permit levels. However, it has been determined that levels greater than 15 μg/l in the mine discharge inhibits the reproductive capabilities of Ceriodaphnia dubia, an invertebrate used to biologically monitor the quality of water of industrial and municipal discharges. The mine is working with the DWQ to mitigate the effects of discharging nickel at concentrations below established discharge limits. No other elements or compounds of concern have been detected in the increased mine water discharge.

The increased mine discharges have been a benefit to Scofield reservoir. Scofield Reservoir has a capacity of 73,600 acre feet of water storage. Currently, the mine discharges approximately 9.2 acre feet of water per day to the lake. Since August 2001, the mine has discharged approximately 21,957 acre feet of water to the lake (March 31, 2003). The mine water discharge not only helps to alleviate some of the problems related to the effects of drought within the Price River drainage area but is also helping to maintain the first class cold water fishery in Scofield Reservoir. Low lake levels in past years have resulted in increased water temperatures and deadly algal blooms. The added water discharged from the mine reduces the potential for algal blooms related to low lake levels.

Currently, Skyline Mine discharges approximately 3,900 gpm of ground water from the James Canyon JC-1 well directly to Electric Lake (JC-2 has not operated as of October 2001). The quality of the water is similar to the water of James, Huntington, Swen's and Little Swen's Creeks, the major tributaries to Electric Lake. TDS concentrations of the well water range between 175 mg/l to 205 mg/l (Appendix A). TDS concentrations in the waters of the tributaries range from 143 mg/l to 274 mg/l (Division EDI, Skyline Mine). Iron, both dissolved and total, concentration in the well water is less than 0.2 mg/l, similar to or less than stream and ground water concentrations in the Electric Lake basin. Nitrogen and phosphorous compounds have not been detected in the well water above background levels. Since the JC-1 well discharges ground water only, it is reasonable to assume that the chemical composition of the water is similar to the waters discharged by the seeps and springs in the area that feed the tributaries of Electric Lake.

The JC-3 well was permitted to discharge water from the mine workings to Electric Lake in July 2003 when PacifiCorp obtained a UPDES permit for the discharge. The pump in JC-3 is capable of producing at least 6,200 gpm. The water chemistry of the groundwater flowing into the 10 Left area of the mine has the same chemistry as the water described above. It is anticipated the chemistry will not significantly change during its short residence time within the mine works prior to being pumped to the surface. The UPDES permit has a limit of 255 mg/l TDS and less than 0.5 mg/l iron concentrations in the discharge water. The discharge water from JC-3 will be monitored for the parameters required by the UPDES permit. Total phosphorous concentrations in the discharge water will be monitored by Canyon Fuel on a quarterly basis. If the water quality of the discharged mine water does not exceed the UPDES quality limits, Electric Lake and Huntington Creek waters will not be degraded. The JC-3 well is anticipated to be operated while drought conditions persist in the area and the mine needs to maintain access to the West Mains. If either conditions changes, modification to the operation schedule of JC-1 and JC-3 may be appropriate. Appropriate regulatory organizations and water users will be notified of the operational changes. The mine anticipates there will be short-lived periods of time where the pumps may be taken off-line for maintenance purposes. Plans have been made underground to handle the increased inflows and discharges should this occur.

Since JC-3became operational and Mine #3 discharge has been suspended, the total discharge of mine water to Eccles Creekhas been reduced by approximately 5,000 to 6,000 gpm. As discussed previously and detailed in Appendix F, over time the overall discharge of mine water to Eccles Creek will be reduced as portions of the mine are abandoned and allowed to flood. The actual mine inflow and discharge rates will probably vary slightly from the numbers given in Appendix F and Appendix J, but the overall downward trend of the rates is expected to continue.

As discussed previously, water from the James Canyon wells is piped directly to Electric Lake. Initially, when the pipeline was laid, the end of the pipe was beneath the surface of the lake. This allowed water to be discharged without disturbing lake sediments. However, as the lake level dropped throughout the late summer and fall of 2001, the end of the pipe was exposed. This resulted in the slow erosion of the accumulated lake sediments in the immediate area of the pipeline discharge. The erosion of the sediments resulted in the moving of the material a short distance away from the pipeline to the standing lake level where they were redeposited. The pre-lake ground surface has been exposed and it consists of sands, gravels and cobbles. This area appears to be naturally well armored and no further erosion is expected to occur. As the lake level rises, the end of the pipe will again be under water.

The capacity of Electric Lake is 31,500 acre feet of water. The reservoir was constructed and is operated by PacifiCorp to maintain a reliable source of cooling water to the Huntington Power Plant. Assuming the James Canyon JC-1 and JC-3 wells pump at a combined rate of 9,000 gpm (a current rate of 3,900 gpm from JC-1 and 5,100 gpm from JC-3), a daily average of approximately 40 acre feet of water would enter the lake. During low flow periods, the volume of water entering Electric Lake from all its tributaries is about 4,000 gpm or less. During high flow periods, inflows may be many times this rate, but accurate inflow records have never been kept. The discharge of the wells to Electric Lake represents 0.12% of the total maximum daily storage capacity of the lake. Since low flow periods generally occur when the lake is at or near its lowest annual level, the well water discharge volume should not significantly affect the daily operation of the reservoir. Indeed, in times of drought, the well water is a significant benefit to both the power company and downstream water users.

The recent drought conditions in the Huntington Creek drainage have resulted in historic low water levels in Electric Lake. This has raised concerns of many of the downstream water users, including PacifiCorp and Huntington Cleveland Irrigation Company. These two entities hold the rights to the water stored in the Huntington Creek drainage. Because of the close proximity of the reservoir to the mine, many naturally have assumed water is entering the mine from the lake. However, age dating of the mine waters, a comparison of the water chemistry of the lake and mine waters, and the low permeability of the formations overlying the coal seam suggest that no direct conduit is present between the lake and the mine (Petersen October 2002). The maximum surface acreage of Electric Lake is 485 acres and a maximum depth of water at the dam is approximately 180 feet. Star Point Sandstone crops out downstream of dam and through Huntington Canyon. The Connelville and O'Connor Faults appear to extend to the south west and into Electric Lake. However, the age-dating and water chemistry data obtained from in-mine water samples does not suggest the faults transmit large volumes of water to the subsurface aquifers intercepted in the mine. Petersen (October 2002) states:

> ".... groundwater flow through the Star Point Sandstone occurs primarily through fracture openings and groundwater flow through the matrix of the sandstone occurs only at a very slow rate. Based on these findings, it is apparent that large volumes of leaking Electric Lake water cannot be the source of the large fault-related inflows in the Skyline Mine. If Electric Lake water was flowing through fractures directly to the 10 Left area, it would be anticipated that the "pulse" of lake water would arrive at the mine in a short period of time. This conclusion is reached because the fracture system in the local area between the lake and the mine has only limited storage potential. Thus, it would be necessary for the potential large volumes of lake water to migrate very rapidly through

the fracture network to accommodate continued water movement from the lake into the fracture system. This condition can be likened to the movement of cars on the interstate freeway during rush hour. Because the total surface area available for cars is limited, the only way to move a large number of vehicles over large distances it to move them rapidly. Calculations of the potential storage capacity of the fracture network in the vicinity of the 10 Left inflow and Electric Lake indicate that were a large inflow of lake water to be migrating through the fracture system, that water should have arrived in the mine in a period of several hours to several days (based on the amount of time required to fill the fracture volume). Based on stable isotopic evidence, solute chemical evidence, tritium concentrations, and radiocarbon contents, it is clear that this is not occurring (i.e., there is not a large slug of modern recharge water anywhere in the Skyline Mine). Similarly, if Electric Lake water were migrating through the pore spaces of the Star Point Sandstone, based on the low hydraulic conductivity of the rock (1.3×10^{-6} to 2.3×10^{-6} cm/sec), it is calculated that the time required for this water to reach the mine workings would likely be measured in the hundreds or thousands of years. Clearly, the lake water could not have migrated through the sandstone pore spaces in the short time that has elapsed since the fracture system was first encountered in the mine."

Skyline Mine continues to study the mine water in-flow problem in an effort to more effectively and efficiently mine coal. The results of these studies are shared with the water right holders and will continue to be shared with the Division.

If operation of the JC-1 and JC-3 wells continues to aid in reducing the overall volume of ground water entering the mine, the well may be operated for the life of mine or until the potentiometric surface of the aquifer has dropped below the mined coal seams. It is reasonable to assume that as the potentiometric surface of the ground water is lowered, the efficiency of the pumps will decrease. This will result in lower rates of water pumped from the wells. Since it appears there is not a direct connection between the water being pumped from the James Canyon wells and surface waters or surface discharges of ground water, continued operation of the wells should not affect the normal discharge rates of these waters. A table illustrating the daily and computed discharge volumes from the James Canyon wells through March 2003 is attached in Appendix A.

Several reaches of Burnout Creek have been undermined beginning in 1993. Prior to mining, a study of the effects of undermining the creek was jointly funded by Skyline Mine and the Manti - La Sal National Forest. The study included monitoring the flows of the stream at several locations, monitoring changes to the stream morphology, and maintaining numerous photo monitoring points over the length of the creek. The study was essentially completed in 1998 and the results reported in 2002 by R.C. Sidle in Environmental Geology, volume 39. The conclusion of the study was that no significant impacts to the stream could be related to mining. Flows were not diminished in the stream and the morphology was not significantly modified by subsidence. Norwest used this report along with additional monitoring data to reach essentially the same conclusion (Appendix B). They found that climatic conditions greatly influenced flows in the creek and found no evidence of water loss due to mining induced subsidence. The graph illustrating the stream flows, as measured at flume 5 near the mouth of Burnout Canyon, from 1991 to the present and the PHDI for the same time period is included in Appendix A. The graphed flows demonstrate the changes in stream flow are heavily influenced by climatic conditions.

Conclusions

Significant new ground water inflows into the mine have been encountered since March 1999. The inflows have resulted in increases in the discharge volume of mine water to Eccles Creek. Additionally, two ground water wells have been drilled in James Canyon and one is being pumped in an effort to reduce the volume of ground water entering the mine. A third well will be pumping water from the 10 Left area of the mine to Electric Lake beginning in May, 2003. The water from these wells is discharged directly to Electric Lake. Continued monitoring of the surface seeps and springs and surface water flows in the permit area demonstrates that the increases in ground water inflows to the mine has not adversely impacted the volume of discharges of ground water to the surface in and adjacent to the mine area. Specifically, monitoring of selected wells, springs, and surface waters in Burnout and James Canyons has demonstrated there is no discernable affect to the flow of these water sources by the increase in ground water inflows to the mine. Indeed, most of the fluctuations in spring flows can be attributed to changes in climatic conditions. Analysis of the monitoring of the aforementioned waters further demonstrates the isolation of the ground water encountered in the mine from surface waters in the mine area as described in the existing PHC.

Increased discharges of mine water to Eccles Creek has resulted in near bank full channel conditions. Significant erosion has not been noted in the stream channel. However, if the high discharge volumes continue, erosion of the stream channel will occur at a rate faster than would occur without the mine water discharge. Since the stream channel is well armored and vegetated, increased bank erosion should still occur only at a very slow rate. The Mud Creek channel will need to be monitored closely for increased rates of erosion. Mitigation efforts may be required for both stream channels if significant erosion is observed. Increased discharges to Scofield Reservoir has helped to alleviate the current drought conditions.

The chemistry of the mine water discharged to Eccles Creek is closely monitored. While TDS concentrations have been reduced in the mine water, the total volume of dissolved solids has increased. The mine is currently working with DWQ in an effort to mitigate TDS and nickel concentrations in the mine water discharge. No other significant chemical impacts due to increased mine water flows have been noted.

Discharges of water from the James Canyon wells should not have a significant impact on the quality of Electric Lake. The well water is piped directly to the lake, thereby eliminating concerns of over loading James Creek. The volume of water discharged to the lake from the wells is a small percentage of the total daily volume of the reservoir. The additional inflows should not adversely impact the operation of the reservoir. In fact, the discharge of ground water and the mine water to Electric Lake should be considered a benefit to the water users in the Huntington Creek drainage.

The operation of JC-3 will benefit the mine since it reduces the overall power, maintenance, and personnel costs associated with discharging mine water to Eccles Creek. If JC-3 were not operated, that volume of mine water would have to be pumped through the mine works and discharged to Eccles Creek. Operation of the well will reduce the discharge of water to Eccles Creek and increase the flow of water to Electric Lake. In times of drought, operation of JC-1 and JC-3 could significantly reduce the chance of the Huntington Power Plant needing to scale back their operations and could result in additional agricultural water to users downstream in Emery County.

FINDINGS OF
GROUND-WATER FLOW MODELING
OF
SKYLINE MINE AND SURROUNDING AREA,
CARBON, SANPETE, AND EMERY COUNTIES,
UTAH

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EXECUTIVE SUMMARY
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1) This report describes the findings of a three-dimensional ground-water flow model that was developed to evaluate the relationship between ground water and surface water in the vicinity of the Skyline Mine. A preliminary version of the model had been constructed solely to predict dewatering requirements for proposed mining in the Flat Canyon tract. This updated and more comprehensive version of the model incorporates data on surface-water hydrology, considerably more ground-water level data, and more detailed information on stratigraphy and structures from a recently completed, sub-regional geologic mapping program.

2) Large, persistent ground-water inflows have been encountered in the Skyline Mine since March 1999. The total inflow rate to the mine from 8 major inflows reached a maximum of more than 10,000 gpm in April 2002, but has since declined to less than 8,000 gpm.

3) PacifiCorp, the operator of Electric Lake, which is located above and west of the mine workings, have questioned whether water flowing into the Skyline Mine is coming from the reservoir. Together with water chemistry, temperature, and inflow-decay data, results of this model suggest that the vast majority of water flowing into Skyline Mine workings comes from the deep ground-water system.

4) The hydrostratigraphy of the study area is dominated by approximately 1,500 ft of Starpoint Formation sandstones and siltstones overlain by an equivalent thickness of shales and siltstones of the Blackhawk Formation. The Skyline Mine extracts coals at the boundary between these two major units.

5) Faults with large vertical displacement (the Pleasant Valley, Gooseberry, Fish Creek Graben, and Valentine Faults, and portions of the O'Connor Fault) impede horizontal ground-water flow, whereas numerous north/south-trending structures of small displacement, including portions of the Connelville Fault, locally transmit water.

6) Ground-water levels in monitoring wells indicate that there are two continuous, but poorly connected ground-water systems in the vicinity of the Skyline Mine. The relatively shallow ground-water system in the Blackhawk Formation is characterized by water levels between 150 and 350 ft below ground surface. A deep aquifer system comprised of the Starpoint Sandstones and coals at the boundary between the Starpoint and Blackhawk Formations exhibits water levels 500 to 1,000 ft below ground surface. Inflows to the mine and ground-water pumping since 1999 have resulted in drawdown of as much as 400 ft over a broad area in the deep aquifer, but they have not affected ground-water levels in the shallow ground-water system.

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7) Pre-mining water-level data indicate that the potentiometric surface of the deep aquifer in the area of the mine had a regional gradient from south-southwest to north-northeast in the range of 0.03 to 0.009 ft/ft. Most of the recharge to the deep aquifer probably occurs in the high country to the south of Huntington and Cleveland Reservoirs. Ground-water discharge is believed to occur in the vicinity of Scofield Reservoir, although direct evidence of the discharge has not been observed.

8) The calibrated ground-water flow model replicates the mine inflows and water levels in monitoring wells quite reasonably. However, the calibration to gaged and estimated stream baseflows is not as good. The calibration to stream baseflows is weakest at the north end of the model where the model-simulated ground-water discharge to streams includes large discrete discharges from the deep aquifer. In reality, the deep discharge is thought to be more diffuse due to a structural setting more complicated than can be represented by this (or any) model.

9) Simulations of the local ground-water/surface-water system with the numerical model indicate that all of the water that has flowed into the Skyline Mine can be accounted for by depletion of storage in the deep Starpoint aquifer system. No shallow ground-water or surface-water source is necessary to account for the inflows. In fact, efforts to "force" surface water from Electric Lake into the mine with the model require unreasonably high values of hydraulic conductivity for the faults beneath the lake.

10) The pre-mining ground-water flow through the deep aquifer system in the area roughly between the O'Connor and Gooseberry Faults is estimated to have been about 5 cfs (2,200 gpm). The model estimates that current mine inflows and pumping have had only a very small effect (about 0.5 cfs or 250 gpm) on the rate of discharge in the area of Scofield Reservoir. The numerical simulations predict that by 2013, this impact will increase to about 2.2 cfs (1,000 gpm).

11) The model also predicts that the inflow rate to the Skyline mine from all sources will decrease by 2013 to approximately 3,700 gpm as a result of diminished hydraulic heads in the deep aquifer system.

1.0 INTRODUCTION

Skyline Mine, operated by Canyon Fuel Company (CFC), is a longwall coal mine located in the northern Wasatch Plateau of central Utah. The mine began operations in the early 1980s; and throughout the development of Levels 1 and 3 (see Figure 1), it encountered ground-water inflows typical of underground coal mines in the western U.S. The inflows were small (less than 300 gpm), usually issued from the roof, and typically would dissipate over one to several months.

Beginning in 1999, mining on Level 2 encountered a number of large, persistent ground-water inflows related to a set of north- to northeast-trending normal faults of relatively small displacement. Initial discharges at individual locations might have been as large as 6,500 gpm, although discharges of about 1,000 gpm were more typical. The discharges at individual fault intersections have decreased slowly, with as much as 30 to 50 percent of the original maximum inflow rate continuing after a period of four years. The total mine inflow reached a peak of about 10,500 gpm in March 2002, and has since decreased to about 7,500 gpm as of March 2003. Figure 1 shows the locations of the major inflows within the Level 2 mine workings.

Mitigation efforts have had only a minor effect on decreasing the inflow rates in the mine. Mining has since been completed in most of Level 2, and ground water has been allowed to flood portions of the 8-Left and 9-Left longwall panels up to seals placed in the entries at the head of 8-Left panel. In consideration of potentially large additional dewatering costs, CFC has put on indefinite hold their plans to develop the proposed Flat Canyon tract (Figure 1).

At the same time that ground-water inflows were disrupting operations in the Skyline Mine, PacifiCorp, the operator of Electric Lake reservoir, reported that water levels in the lake were declining at what they perceived to be an anomalously rapid rate. The high-water line of Electric Lake lies about 600 ft above, and about 2,400 ft west of the 10-Left entries. PacifiCorp concluded that water from Electric Lake was entering the Skyline Mine.

Results of water chemistry analyses continue to indicate that ground waters entering the mine and being pumped from the James Canyon wells are from a very old, deep source, and contain, at most, a small fraction of shallow ground water. Furthermore, dye-injection tests carried out by PacifiCorp also have shown no connection between the lake and the mine inflows and pumping wells (PacifiCorp, 2003).

1.1 PREVIOUS WORK

Hydrologic Consultants, Inc. of Colorado (HCI) submitted an initial progress report (HCI, 2001) to CFC in December 2001 describing the findings of a preliminary hydrogeologic investigation and the results of efforts to mitigate the large inflow at 10-Left. The report included the preliminary results of water chemistry analyses indicating that ground waters entering the mine and being pumped from the James Canyon wells are isotopically distinct from surface waters. HCI (2001) also included a description of the results of pumping from the James Canyon wells, a compilation of water-level data from monitoring wells, and a preliminary analysis of changes in monitoring-well water levels attributable to the mine inflows. A second progress report (HCI, 2002a) included a more encompassing investigation of geologic structures and stratigraphy beneath the mine site and concluded that the shallow and deep ground-water flow systems in the mine area responded separately to hydraulic stresses. HCI (2002a) also included additional analysis of the effects of pumping from the James Canyon wells on mine inflows.

A third progress report (HCI, 2003) summarized HCI's further analysis of hydrogeologic data collected since the largest of the mine inflows began and presented a preliminary assessment of the interaction between the surface water and the deep ground-water flow system. HCI's interpretation of the apparent structural compartmentalization within the deep aquifer, the pre-mining and early-mining ground-water conditions in the area, and the locations of recharge to and discharge from the deep aquifer were also described. In addition, HCI (2003) summarized the surface-water hydrology in the area above the mine, and evaluated the hydraulic parameters of key hydrostratigraphic units.

An early version of a ground-water flow model was completed in May 2002 for the limited purpose of predicting dewatering requirements for mining in the Flat Canyon Tract. For that purpose and to save time and costs, the early model version did not include surface-water hydrology and included a no-flow top boundary to represent the thick, relatively-impermeable Blackhawk Formation above the mine. The assumption of no-flow through the Blackhawk Formation was based on findings of geochemical and geological studies at other sites in Utah (Mayo, and Morris, 2000) which indicate that the deep ground waters that provide inflows to the mine are much older than and do not receive a significant amount of recharge from the shallow ground-water system that, in turn, receives recharge from precipitation.

The results of the early model were presented at a meeting at Skyline Mine on 31 May 2002. The model did not predict the dewatering requirements for a "dry" mine, but rather the amount of active dewatering that would have to be implemented to keep residual passive inflows to a manageable rate. In August 2002, CFC requested HCI to update the ground-water flow model with additional water-level data, and to incorporate surface-water effects (specifically surface recharge to the ground-water system) in order to achieve the objectives stated above. HCI identified four specific tasks that had to be completed in order to revise the model:

1) Incorporation of more accurate stratigraphy and fault locations to simulate the outcrops of sandstones in areas of potential recharge/discharge.

2) Incorporation of surface topography. The strata would be "hung" as before on the LOB coal layer; but with the new model, the topmost overburden units would be extended to the ground surface.

3) Definition of streams on the top surface of the model as drain nodes at elevations defined by the topography.

4) Calculation of recharge to the ground-water system from orographically controlled precipitation.

Incorporation of detailed stratigraphy and geologic structures proved to be the most time-consuming aspect of the model update, and modeling work had to be put on hold awaiting completion of a separate study by Kravits (2003). The modeling re-started in March 2003, and the initial results demonstrated extreme sensitivity to the boundary conditions to the south of the model domain. Consequently, the modeling was again put on hold from June until September 2003 until the stratigraphy and structures in the area south of Electric Lake could be better defined and incorporated into the model.

1.2 CURRENT INVESTIGATION

The goal of the current investigation is to develop a hydrogeologically-based numerical ground-water flow model that can:

1) describe the ground-water system in the vicinity of the Skyline Mine,
2) be used as a management tool for both the ground-water and surface-water resources of the region, and
3) evaluate significantly different explanations of the source of ground water flowing into the mine.

As the typical first step in building a numerical ground-water flow model, a conceptual hydrogeologic model is developed that is based on regional and local geology, data from drillholes and hydraulic testing, and long-term monitoring of water levels, stream flows, etc. However, as will be evident below, many of the components necessary for the Skyline model are not well defined. Water-level data are sparse in both the shallow ground-water system and the deep Starpoint aquifer (described below). Other conceptual components with considerable uncertainty (since no pumping tests have yet been done in the Blackhawk or Starpoint Formations) are the values for hydraulic conductivity for each of these major hydrogeologic units, and relative permeabilities of the major structures.

Consequently, the conceptual hydrogeologic model of the Skyline Mine area is still being developed. Although some components such as recharge or stratigraphic thicknesses can be reasonably well defined by the available data, other major components such as the vertical hydraulic conductivity of overburden units or the hydraulic characteristics of faults can only be evaluated from the reasonableness of the results of preliminary numerical simulations using assumed values. As such, the Skyline model is still in a heuristic stage in which it is being used to learn about the characteristics of the regional ground-water flow system. Nonetheless, it is also being used at the same time to predict hydrologic outcomes under alternative assumptions.

2.0 HYDROLOGIC SETTING

The hydrologic study area (HSA) is centered on the Skyline Mine in the northern Wasatch Plateau of central Utah. It generally lies west of Pleasant Valley and the towns of Scofield and Clear Creek and east of Gooseberry Valley and Skyline Drive. The HSA extends south to the Paradise Creek Valley divide in Joe's Valley and north to the confluence of Gooseberry and Fish Creeks (Plate I).

The HSA is comprised mostly of high, somewhat flat-topped mountains with deeply incised, heavily wooded valleys. It is characterized by considerable relief with elevations ranging from 7,700 ft (NGVD) at the mouth of Fish Creek to more than 10,000 ft at the headwaters of Left Fork of Huntington Creek (Plate I). Ephemeral streams on the west and east flanks of the HSA flow northward and discharge through Scofield Reservoir, while streams in the center of the HSA flow southward and discharge through Electric Lake Reservoir.

2.1 STRATIGRAPHY

The HSA straddles the western margin of the Cretaceous Western Interior epi-continental seaway. Subsidence along the western edge of the basin during most of Cretaceous time coincided with orogeny along the Sevier Belt to the west, and resulted in a thick accumulation of terrigenous clastic sediments shed eastward into deeper-water environments. The stratigraphic units of greatest interest in this study, the Mancos Shale, Starpoint Sandstone, and Blackhawk Formation, are all of upper Cretaceous age. The Mancos shale demarks the bottom of the model, as described below, and is of marine origin. Deposition of the Starpoint Sandstone above the Mancos Shale represents a general regression of the sea, and shallow-water deposition for an extended period along a stable shoreline. Deposition of the Blackhawk Formation culminated the regression of the sea as pro-grading delta and coastal swamp sediments, including overbank muds, channel sands, and coals, rode over the beach deposits.

CFC has mapped and compiled the geology in the region around the Skyline Mine, and their interpretation of the geologic relationships and principal structures (CFC, 2002) is shown on Plate II. The Skyline Mine is developed in the O'Connor and Flat Canyon coals, members of the Blackhawk and Starpoint Formations, respectively. The overburden consists primarily of siltstones, sandstones, coals, and shales of the Blackhawk Formation. Sandstones, subordinate to the shales and siltstones, generally occur in elongate bodies, and represent distributary channel deposits. The Blackhawk Formation is overlain by later Cretaceous and early Tertiary continental sedimentary rocks in the high country west and south of Electric Lake (Units of the North Horn and Price River Formations). The upper sedimentary units are not distinguished from Blackhawk Formation overburden in the model.

Units underlying the principal coals include interbedded siltstones and sandstones interpreted to be a stacked transgressive-regressive shoreline assemblage. The two proximal sandstone units beneath the coal seams, and hence the two most well known, are the Storrs and Panther Sandstones (Figure 2). The Storrs and Panther sandstones are each about 40 to 60 ft thick, and are separated by approximately 30 ft of shale and coal.

Numerous additional shoreface sandstone units locally underlie the Panther Sandstone. The log of one nearby drillhole (reproduced in Figure 2) shows a stacked sequence of sandstones totaling at least 800 ft in aggregate thickness within a total stratigraphic thickness of 1,100 ft. CFC has interpreted the sandstones represented in the log to be of shoreface affinity (M. Bunnell, 2002, personal commun.). Regional studies have shown that the individual sandstone bodies within the Starpoint Formation are elongate in a north-south direction, parallel to the ancient shoreline, and interfinger seaward (to the east) with the Mancos Shale and landward with Blackhawk sediments (Flores et al., 1984).

Kravits (2003) compiled the logs of 17 deep gas exploration boreholes and about 30 coal exploration boreholes in the northern Wasatch Plateau. He found that the Starpoint Sandstones, as described above, extend beneath and beyond the boundaries of the model domain. The total thickness of the Starpoint Formation increases and decreases locally, within a range of 200 to 1,500 ft. The formation is thickest along a north-northeast axis running through the approximate center of the HSA and thins both eastward and westward. The proportion of sandstone vs. shale in the Starpoint Formation varies from about 70:30 to about 90:10, with the highest proportion occurring where the formation is thickest. The stratigraphic data from Kravits (2003) including elevations of various units, thicknesses, and sandstone/shale ratios have been incorporated into the model.

2.2 STRUCTURE

Strata in the HSA generally dip at a shallow angle to the west and are locally folded in subdued, open folds. The strata in the vicinity of the Skyline Mine dip in three directions away from the portal at a fairly constant angle of about 4 degrees. Numerous faults cut the sedimentary rocks in the vicinity of Skyline Mine. The major faults include the generally north-south trending Pleasant Valley Fault Zone along Mud Creek to the east of the HSA and the Gooseberry Fault Zone in Gooseberry Creek to the west (Plate II). The vertical components of displacement across these two major faults have been estimated to be several hundred feet to more than 1,000 ft, respectively. Roughly east-west striking faults comprise the Fish Creek graben at the north end of the HSA. Vertical displacements on both of the faults bounding the Fish Creek graben are estimated to be 800 to 1,200 ft (Kravits, 2003).

Three intermediate- to large-magnitude faults in the interior of the HSA (between the Pleasant Valley and Gooseberry Faults) include the Connelville, O'Connor, and Valentine Faults, all to the east of the mine workings (Plate II). The three faults strike north-south to northeast-southwest; and according to Kravits (2003), all of them appear to have differential displacement along their strikes (i.e., they are "hinge" faults). The Connelville Fault defines the southeast boundary of the Skyline Mine and the northwest boundary of the White Oak Mine (Figure 1). The Connelville Fault exhibits about 250 ft of vertical displacement along its trace from Scofield south to Electric Lake. South of Electric Lake, the displacement increases rapidly to as much as 1,300 ft in Joe's Valley.

The relative displacement on both the O'Connor and Connelville Faults is down to the west. However, the "hinge" direction is opposite in the two faults. The O'Connor Fault exhibits at least 600 ft of displacement along its trace from Pleasant Valley south to Electric Lake, but only about 100 ft of displacement south of Electric Lake. The O'Connor and Connelville Faults appear to join near Miller Flat Reservoir in Joe's Valley. The Valentine Fault occurs just east of the O'Connor Fault, and it also has downward displacement to the west. Along the trace of the Valentine Fault on the west slopes of Pleasant Valley, the displacement might be as little as 200 ft. To the south, however, the displacement increases to as much as 1,400 ft where the Valentine forms the western boundary of the Joe's Valley graben.

A number of lesser faults and fracture zones also occur between the Pleasant Valley and Gooseberry Creek Faults, many of which have been encountered in the workings of Skyline Mine (Plate III). In the Level 2 mine, the 11-Left, 14-Left, and 16-Left Faults trend northeast-southwest, at an angle to the Pleasant Valley and Gooseberry Creek Faults, but parallel to the Connelville Fault (Plate II). The Diagonal Fault trends north-south, parallel to the regional faults, and apparently intersects both the Connelville and 14-Left Faults. The Diagonal Fault is the largest of the faults that have been encountered in the mine and exhibits as much as 60 ft of vertical displacement. The 14-Left and 16-Left Faults locally show only about 10 ft of vertical displacement.

In the Level 3 and Winter Quarters mine areas, no significant north- or northeast-trending faults have been mapped. CFC's structural interpretation shows mostly east-west trending faults of minor displacement north of the Level 2 workings. The West Mains Fault is the most prominent east-west fault and has about 30 ft of vertical displacement. East-west trending igneous dikes locally accompany the east-west faults (Plate III). CFC's geologic maps suggest that the north- and northeast-trending faults cut the dikes.

2.3 PRECIPITATION AND EVAPOTRANSPIRATION

A weather station maintained below Electric Lake Dam is at an elevation of 8,400 ft, and two nearby stations, Mammoth-Cottonwood and Red Pine Ridge, lie at elevations of 8,800 and 9,200 ft, respectively. Average annual precipitation at these weather stations over a 23-year period (1978 to 2001) ranges from about 24 inches at Electric Lake up to 32.4 inches at Red Pine Ridge. Regression analysis of a plot of average precipitation at the three weather stations vs. elevation defines a relationship from which average precipitation can be estimated for different elevations within the HSA:

$$P = 0.0105 \cdot z - 63.9 \tag{1}$$

where:

P = average annual precipitation (inches), and
z = average elevation of land surface (ft, NGVD).

The correlation coefficient, R^2, for this relationship is 0.988. Estimates of average annual precipitation range from 41 in/year at an elevation of 10,000 ft to 18 in/year at 7,800 ft near the town of Scofield. Precipitation is highest in November through March, and lowest in June-July.

HCI estimated the evapotranspiration (*Et*) rate for the forests within the HSA to be approximately 65 percent and for the grass/sage to be 35 percent (HCI, 2002b). Within the forests, aspen comprises about half of the forest cover, and spruce/fir comprise the remaining half. Using these vegetation coverage estimates, the average potential evapotranspiration rate across the HSA is about 15.2 inches per year.

2.4 SURFACE WATER

The HSA is drained by three major streams:

1) Fish Creek (including Gooseberry Creek) that drains the west side of the domain, flowing northward and then eastward into Scofield Reservoir.

2) Mud Creek that drains the eastern side of the domain, also flowing northward into Scofield Reservoir.

3) Huntington Creek, including the Left Fork, that drains the center of the domain. Its main fork flows southward through Electric Lake Reservoir, while the Left Fork flows westward and southward to join the main fork below the dam.

The streamflows peak in May-June with spring runoff, and the lowest flows occur in December and January. October mean flows, generally considered to represent baseflow in the western interior U.S., span wide ranges for all three major streams as a consequence of relatively wet autumns in the HSA. Nevertheless, baseflows computed from October average flows are shown in Table 1.

The HSA includes five reservoirs, Electric Lake, Huntington, Cleveland, Miller Flats, and Rolfson Reservoirs. At high water, Electric Lake covers about 430 acres. The remaining four reservoirs range in surface area (at high water) from about 40 to about 140 acres. Scofield Reservoir lies just outside the northeast boundary of the HSA.

2.5 GROUND WATER

2.5.1 Monitoring Network

Current shallow ground-water level data are available from four monitoring wells (W79-26-1, 79-10-1b, 79-14-2a, and 79-35-1b). In addition, records from shallow monitoring well 79-22-2-1 are available from 1982 through at least 1991. Plate I shows the locations, and Table 2 lists coordinates, elevations, and screened intervals of all known ground-water monitoring wells.

Deep ground-water level data are available from 13 currently serviceable monitoring wells (Plate I). At least half of these wells, however, were constructed after significant ground-water inflows had been encountered by mining. In addition, some historic water level records are available from monitoring wells that have since failed. Electronic monitoring devices have been used to record water levels in six monitoring wells (Table 2).

2.5.2 Current Ground-Water Levels

The shallow monitoring wells in the HSA measure water levels both in the shallow ground-water system within the Blackhawk Formation including some discontinuous and locally perched zones of ground water. Water levels in monitoring wells such as 79-10-1b, 79-22-1, and 79-35-1b (Table 2) represent the continuous shallow ground-water system. In these wells, the water levels occur at 150 to 350 ft below ground surface (bgs) and generally do not respond to seasonal conditions. The shallow water levels correlate from drillhole to drillhole (although the data are sparse) and generally define a water table that approximately mimics topography. In the HSA, the current water table shows relief of nearly 500 ft, with the highest water level elevation (9,032 ft) measured in well 79-10-1b on the high ridge between Huntington and Winter Quarters Canyons and the lowest water level elevation (8,565 ft) measured in 79-35-1b in the bottom of Burnout Canyon.

Underground mining in the HSA appears to have had local, measurable effects on water levels in the shallow ground-water system. Large, relatively short-term oscillations are apparent in the hydrographs of some shallow wells (Figure 3), and are most likely the result of subsidence-induced changes in porosity (or storage) as mining passes under the area and the subsequent recovery due to recharge. The hydrographs of the shallow wells in Figure 3 do not show the continuous decline in water levels in response to the large inflows in the Level 2 mine that the hydrographs of the deeper monitoring wells clearly exhibit.

The deep ground-water system beneath the HSA has been variously described as the "regional aquifer," the "Blackhawk/Starpoint aquifer," or just the "Starpoint aquifer." In this study, it will be simply referred to as the "deep aquifer." It should be clearly understood that the shallow ground-water system (excluding locally perched groundwater) and deep aquifer are components of a continuous ground-water system and are not hydraulically disconnected. However, because of the significant amount of low hydraulic conductivity material between them, the two systems respond to hydraulic stresses quite differently.

The deep aquifer is represented by water levels measured in wells that are screened in the Upper O'Connor (UC), Lower O'Connor B (LOB), Lower O'Connor A (LOA), and Flat Canyon coals and in the laterally continuous sandstone units between and beneath these coals (i.e., the Storrs, Panther, and Starpoint Sandstones). Ground-water levels in the deep system are generally 50 to 500 ft lower than in the overlying shallow Blackhawk aquifer, depending on topography and on the relative depths of the well screens. As can be seen in Figure 3, water levels in the deep monitoring wells have drawn down significantly beginning in 1999 (at about the time that large inflows were first encountered in the Level 2 Mine). Figure 4 shows the potentiometric surface in the deep system near the Skyline mine as of April 2003.

2.5.3 Pre-Mining Ground-Water Levels

HCI (2003) included a compilation of pre-mining water levels measured in 11 of the deep monitoring wells within the HSA. Earlier investigations that reported or discussed some pre-mining water-level measurements included Vaughn Hansen Associates (1979, 1981, and 1982), Coastal (1992), and Norwest (2000). In general, "pre-mining" refers to conditions prior to opening of the Skyline Mine in the early 1980's. However, hydrologic data from the 1970's and early 1980's are sparse, so that in some instances pre-mining conditions refer to those prior to the advent of large mine inflows beginning in 1999. Even these water level data are sparse, however, and HCI (2003) included in the compilation some estimates of pre-mining conditions projected from post-mining drawdown trends in recently constructed monitoring wells. Other pre-mining water levels were rejected by HCI because of documented damage to wells resulting in eccentric water level measurements. Most water levels included in the compilation represent conditions in the LOB (or equivalent coal) and in the first sandstone below the LOB. Some deep wells, particularly in the far northern part of the HSA, were screened in the uppermost Starpoint Sandstone units.

The compiled pre-mining water-level data are plotted and have been contoured in Figure 5. This interpretation indicates that ground water in the deep aquifer (i.e., in the LOB coal and underlying sandstones) generally flows from south-southwest to north-northeast beneath the Skyline Mine. The pre-mining ground-water gradient indicated in Figure 5 ranges from about 0.03 ft/ft in the northern part of the HSA to as low as 0.009 ft/ft in the area around the Skyline Mine.

This interpreted pre-mining potentiometric surface indicates that the majority of recharge to the deep system probably occurs in the southwest of the HSA, in the high country south of Huntington Reservoir. Discharge must occur downgradient, in the direction of Scofield Reservoir. As discussed in HCI (2003), there is yet no direct evidence from stream or spring gaging of the actual location of the ground-water discharge. Because of the major stratigraphic offsets, it is considered unlikely that the ground water would continue flowing northeastward through the Fish Creek and Pleasant Valley grabens. It is more likely that discharge is diffuse, and occurs beneath the alluvium and marshes of Scofield Reservoir, and is thus ungaged.

2.6 PUMPING AND GROUND-WATER DISCHARGE TO MINE

2.6.1 Mine Inflows

The Winter Quarters tract was mined from the turn of the century through the 1930's, and the workings were reportedly relatively dry (although detailed inflow data do not exist). The Skyline Level 3 Mine lies to the south and west of the old Winter Quarters Mine, and was worked from 1982 through 1996. The Level 3 Mine also encountered very little ground water, at least relative to the later inflows to the Level 2 Mine. The so-called "large" inflows in the Level 3 Mine ranged from 100 to 300 gpm, and they usually decreased over several weeks to 10 gpm or less. Mining in the Level 1 Mine (directly above the northeast half of Level 2 Mine) also encountered little ground water during the period 1989 through 1998. Consequently, from 1982 to 1999, the total discharge of ground water to the Skyline Mine ranged between 200 and 500 gpm. Mining in Level 2 of the Skyline Mine began in 1996 and continues to present. Large, persistent inflows were first encountered in Level 2 beginning in 1999. Figure 6 shows the increases in ground-water inflows to the Level 2 workings from March 1999 through April 2003.

Mining encountered an inflow of 1,600 gpm from the floor of the entry in the 14-Left headgate in March 1999 (Plate III). In December of the same year, another similar inflow of 1,200 gpm was encountered in the 16-Left headgate. A third large inflow of about 1,000 gpm was encountered in the West Submains crossing of the Diagonal Fault in March 2001.

Mining in the 10-Left area encountered a sudden inflow of about 1,200 gpm issuing from a fracture zone in the walls and floor of the entry on August 9, 2001. Seven days later, mining in an adjacent entry encountered an additional 2,700 gpm from the same structure. The combined inflows to the two entries comprise the nominal 10-Left inflow. The total rate of inflow at 10-Left increased to about 6,500 gpm for a short time during the drilling of a nearby large-diameter well, but decreased back to about 4,200 gpm when the well was grouted. Since mid-September 2001, the 10-Left inflow has declined to less than 3,000 gpm.

Mining west of the Diagonal Fault since September 2001 encountered some additional significant inflows in the East Submains (initially 1,000 gpm), and at three other locations associated with three parallel faults cutting the 11-Left panel (Plate III). The 11-Left inflows initially totaled 3,500 gpm, but temporarily increased as longwall mining exposed a long reach of one of the faults.

Flow rates of the individual large, Level 2 inflows have only occasionally been measured directly. More commonly, flow rates have been estimated from power usage of pumps and by stage-volume observations in the flooding mine workings. Waters from the individual inflows since about September 2002 have flowed together in several locations, and the flow rates have since been estimated from the manifolded pumpage. Table 3 summarizes the dates when first encountered, the elevations, and both the initial and March 2003 inflow rates for the largest and relatively sustained inflows to the Level 2 Mine. The total inflow based on metered mine discharge in February 2003 was 7,850 gpm.

Descriptions of the physical characteristics of the inflows and the chemistry of the inflowing water are provided in HCI (2003). Two kinds of inflows have been encountered in the Skyline Mine. The most common, which have occurred in all three levels of the mine, discharge from the roofs of the entries, usually from channel sandstones lying immediately above the coal. These inflows typically decrease significantly and often "dry up" within a few weeks. The second kind -- the large inflows to the Level 2 workings from the floor and walls of the workings -- do not decrease appreciably with time. All of the large inflows to the Level 2 workings are associated with north- to northeast-trending faults of relatively little vertical or lateral displacement.

The chemistry of the large inflows to the Level 2 workings has been compared extensively to the chemistry of surface-water samples from streams, springs, and Electric Lake (HCI, 2001; Mayo Associates, 2002). Both the major ion and isotopic compositions are significantly different in the mine water than in the surface waters. In addition, analyses of ^{14}C content clearly indicate that the waters from the mine and Electric Lake are of different ages. Tritium (^{3}H), which was released in large quantities to the atmosphere during the above ground testing of nuclear bombs in the early 1950s, is present in most surface and shallow ground waters throughout the world. Consequently, tritium concentrations have been analyzed in numerous surface- and ground-water samples since the initial inflow at 10-Left began. Samples from Electric Lake have consistently contained tritium in the range of 8 to 12 tritium units (TU). The tritium content of the mine inflow samples and the discharge of well JC-1 indicate tritium in the range of 1 to 2 TU. Thus, the tritium analyses of inflow and pumping samples suggest that these contain deep ground water with only a small component of water that originated at or near the surface.

Temperature provides another clear distinction between near-surface water and the mine inflows. The temperature of the water in the deeper parts of Electric Lake is about 9.6°C. The ambient temperature of the Level 2 Mine is about 8.9°C, and the temperatures of the relatively small inflows coming from channel sandstones in the roof of the mine and other roof "drips" has also averaged about 8.9°C. In contrast, the temperatures of the large, persistent inflows range from 13.2° to 15.9°C. Mayo and Associates (2002) conclude that these higher temperatures indicate the source of the large inflows might be 600 to 1,000 ft below the level of the workings.

2.6.2 Pumping from Dewatering Wells

During September and October 2001, two large diameter wells -- designated JC-1 and JC-2 -- were drilled from the surface immediately above the inflow in 10-Left in an attempt to intercept as much of the ground water as possible before it flowed into the mine. Both wells were drilled in James Canyon in Section 35, T13S, R6E (Plate III). Drilling methods, geological intercepts, and well completions for both wells are described in detail in HCI (2002a). Both JC-1 and JC-2 were completed in the Storrs Sandstone; JC-1 in a highly-porous splay of the Diagonal Fault, and JC-2 in an unfractured zone. Because of disappointingly low yield, JC-2 has not been pumped for any significant length of time. The historic pumping of JC-1 is shown in Figure 7.

A third dewatering well was completed into the 10-Left workings in April of 2003. JC-3 pumps directly from the pool of standing water in the mine workings; and, thus, has only a small, indirect effect on ground-water flow. Consequently, well JC-3 is not simulated in the model.

3.0 CONCEPTUAL HYDROGEOLOGIC MODEL

The available geologic, hydrologic, and climatologic data were incorporated into a conceptual hydrogeologic model that describes the surface-water and ground-water flow systems within the HSA. The conceptual hydrogeologic model is the descriptive physical analogue of the hydrologic system that the numerical model (described below) mathematically simulates. The essential components of the conceptual model include:

- hydrologic boundaries (ground-water divides, rivers, major aquacludes, etc.),
- the areal and vertical extent and hydraulic characteristics of the primary hydrogeologic units,
- hydrologically significant structures (i.e., faults),
- recharge to the HSA,
- perennial streams and reservoirs, and their interaction with the regional ground-water system,
- ground-water pumping (including mine inflows),
- mining and its hydrologically-significant consequences,

The following paragraphs describe the principal conceptual components. Section 4.0 will describe how these components have been incorporated into or used to calibrate the numerical model.

3.1 HYDROSTRATIGRAPHIC UNITS

Eleven geologic units, shown in the hydrostratigraphic column in Figure 8, have been differentiated in the HSA. In general, from shallowest to deepest, they are:

1) Overburden,

2) Upper O'Connor seam (UO),
3) Interburden 1,
4) Lower O'Connor B seam (LOB),
5) Interburden 2,
6) Storrs Sandstone,
7) Interburden 3,
8) Panther Sandstone,
9) Interburden 4,
10) Starpoint Sandstone, and
11) Mancos Shale.

The Mancos shale is discretely represented only where it crops out in lower Huntington and Left Fork Canyons; elsewhere, it is implied as the basement to the ground-water flow system with a very low hydraulic conductivity. Furthermore, the overburden and Starpoint units are divided into multiple layers in the model. Consequently, the model incorporates a total of 13 layers.

The sections below describe the available test data and other bases for estimating the hydraulic properties of the various hydrostratigraphic units. The hydraulic properties of all hydrostratigraphic units used in the model are summarized in Table 4.

3.1.1 Overburden and Interburden units

Overburden comprises the top two geologic layers of the model, which together locally represent over 2,000 ft of Blackhawk Formation siltstones and shales. Differentiation of the thin upper unit from the much thicker lower overburden is necessary in order to model an uppermost zone with a much greater hydraulic conductivity (Mayo and Morris, 2000) than the materials below. As shown in Figure 8, the lower overburden is subdivided into two to four model layers, depending on location (two where UO coal is modeled, and four where the UO coal layer does not exist). The additional model layers are necessary to model the propagation of fractures upward into overburden as mining progresses. A relatively low value of hydraulic conductivity is assigned to the lower overburden.

Few data are available on the hydraulic properties of the overburden. Laboratory permeability tests of cores of the Blackhawk shales and siltstones conducted by DOGM (2001) indicated values of both horizontal and vertical hydraulic conductivity (K) on the order of 10^{-8} ft/day to 10^{-7} ft/day, respectively. It should be recognized, however, that laboratory tests are conducted on intact samples of core and do not reflect the contributions of fractures or bedding plane discontinuities to the bulk hydraulic conductivity of the formation. Thus, laboratory tests of cores almost always yield values of K much lower than values determined by hydrologic testing of the bulk material in the field.

In the model, the lower overburden unit, which represents the bulk of the Blackhawk Formation, is assigned a horizontal hydraulic conductivity (K_h) value of 10^{-3} ft/day. The vertical hydraulic conductivity (K_v) is assigned a value of 4×10^{-4} ft/day. These values are as much as 4 orders of magnitude higher than the values derived from core tests. However, in order to conservatively allow for the greatest possible migration of water from the surface to depth, high, but still reasonable, values of K_h and K_v were chosen. These values are the highest that could be assigned in the model without simulating significant drawdown in shallow monitoring wells that, in the field, show no drawdown.

The upper overburden in the model (modeled as approximately 150 ft thick) is assigned much higher $K_h = K_v$ values 1 ft/day. (The uppermost layer is assumed to be isotropic.) These high values allow through-flow of shallow ground-water recharge to match streamflows. This very permeable surface layer represents the zone where weathering and stress-relief fracturing have resulted in enhanced hydraulic conductivity, and is commonly referred to as the "active zone" of ground-water movement (Mayo and Morris, 2000).

In transient runs, the lowest of the multiple layers representing lower overburden is locally converted to a higher-conductivity material representing fractured and collapsed "gob" above the mined coal. The gob is approximately 100 ft thick (8 times the thickness of the coal) and is assigned K values 10 times greater than the values in the lower overburden. The four interburden layers (between the coals and the sandstones) also represent shales and siltstones. The first interburden is assigned properties similar to the lower Blackhawk overburden unit. The lower three interburden layers having a slightly lower vertical hydraulic conductivity.

3.1.2 Coals and Upper Sandstones

Two coal units (the UO and LOB) are simulated in the model. The upper coal is differentiated in order to account for early mining and mine inflows. The two coal units are assumed to have relatively high horizontal hydraulic conductivity (similar to a sandstone) and to be isotropic, the result of fractures or cleats.

The Storrs and Panther Sandstones are modeled as separate units, with interburden between. A relatively high hydraulic conductivity of 1 ft/day is assigned to the Storrs and Panther sandstones based on the results of pumping in James Canyon (HCI, 2003). Both sandstones are assumed to be isotropic, resulting from the offsetting effects of bedding plane discontinuities and high-angle fractures.

Vaughn Hansen Associates (1982) conducted a series of short-duration, single-well drawdown recovery tests in the Lower O'Connor coal and Aberdeen Sandstone (equivalent to the combined Storrs/Panther sandstones) beneath lower Winter Quarters Canyon. They estimated the hydraulic conductivity of the coals and underlying sandstones to range from 1 to 3 ft/day. These values would, of course, reflect aquifer conditions in only a relatively small area around the well screens. Nevertheless, HCI considers the values to be reasonable for moderately fractured, partially cemented, fine-grained sandstone. These K values are similar to values derived more recently by HCI (2003).

3.1.3 Starpoint Sandstone

Kravits (2003) found that the Starpoint Formation varies in thickness and composition across the HSA. Beneath the Skyline Mine, it consists of at least 10 stacked sandstones, with a combined thickness of 1,200 ft, separated by siltstone/shale units. The thickness of the entire formation is about 1,500 ft thick. For simplicity, the formation is modeled as a homogenous unit with thickness varied from 500 to 1500 ft, bulk properties of K and specific storage (S_s) that account for both the sandstone and shale components, and a horizontal/vertical anisotropy ratio of 5:1. The Starpoint hydrostratigraphic unit is divided into upper and lower numerical layers in the model in order to avoid a very thick element above the bottom boundary of the model.

Laboratory permeability tests of cores of the Starpoint Sandstone conducted by DOGM (2001) indicated both horizontal and vertical K values to be on the order of 0.01 ft/day. As described previously, however, laboratory tests conducted on intact samples of core do not accurately reflect the contributions of fractures to the overall hydraulic conductivity, and therefore, generally yield values of K much lower than values determined by hydrologic testing of the bulk material in the field.

HCI (2003) estimated the average, or bulk, parameters for the Starpoint Formation using several analytical techniques to evaluate long-term pumping and monitoring data. The bulk K in the vicinity of Skyline Mine was found to be about 2 ft/day, and the specific storage was found to be about 6×10^{-6} ft^{-1}. These hydraulic conductivity values are derived primarily from responses in monitoring wells and pumping wells within the zone of north-south fracturing that is the location of all major mine inflows in the Skyline Mine. Conversely, HCI assumes K values of about 1 ft/day in the Starpoint Formation outside of the zone of north-south fracturing (to the north), where historic inflows were much smaller.

3.2 HYDRAULIC CONDUCTIVITY OF FAULTS AND FRACTURES

Plate II shows the structures that are included in the conceptual hydrogeologic and numerical ground-water models. Within the model, these structures have been differentiated into:

1) large-displacement, bounding faults,
2) intermediate-displacement faults, and
3) small-displacement faults.

The Gooseberry, Fish Creek, and Pleasant Valley Faults are so-called large-displacement faults with displacements on the order of many hundred to several thousand feet. They influence the movement of ground water by offsetting hydrogeologic units of significantly different hydraulic characteristics. In each case, the faults juxtapose relatively permeable Starpoint sandstones against the lower-permeability Blackhawk Formation (Kravits, 2003). Consequently, these model-bounding faults are assumed to prevent lateral ground-water flow throughout the entire model thickness, and as will be discussed in Section 4.3, are assumed to be no-flow boundaries. However, because of presumed brecciated zones associated with the faults, water can move vertically within the fault zones.

The relative hydraulic conductivity of the small- and intermediate-displacement faults in the interior of the HSA is assumed to be a function of both a) the magnitude of displacement and b) the hydraulic conductivity of the stratigraphic unit through which the structure cuts. In general, it is assumed that smaller-magnitude displacements (i.e., less than about 200 ft) result in more open, broken fault zones, and larger-magnitude displacements (those greater than 200 ft) result in gouge-filled, low-permeability fault zones. Furthermore, sandstones and coals are presumed to undergo brittle deformation within the fault zones whereas the siltstones and shales behave plastically. Consequently, a small- to intermediate-displacement fault is characterized by relatively high hydraulic conductivity in the deep sandstone-dominated units and relatively low hydraulic conductivity in the Blackhawk Formation units.

The small-displacement faults within the model domain, shown in Plates II and III, include the West Mains, Gooseberry South, Diagonal, 16-Left, 14-Left, and 11-Left-a, 11-Left-b, and 11-Left-c Faults. All large, persistent ground-water inflows in the Skyline Mine to date have been associated with these faults. Except as described below, the small-displacement faults are assigned K_h values of 0.001 ft/day in their upper portions (within the overburden) and K_h values of 1.0 ft/day within the sandstone units (below the LOB). The Diagonal Fault is assigned a K_h value in the sandstone of 10 ft/day generally, and 20 ft/day beneath the mine. As will be described in more detail in Section 5.1, the upper portion of the Diagonal Fault was assigned a range of K values under Electric Lake in the sensitivity analysis of the possible impact to Electric Lake during mining (Section 5.1).

The intermediate-displacement faults within the model domain include the Valentine, O'Connor, and Connelville Faults. The hydraulic properties of these larger interior faults control the ground-water flow directions, and in predicting the flow of ground water from potential sources to the inflow points in the Skyline Mine.

The Valentine Fault is assumed to localize as much as 1,400 ft of vertical displacement across its trace. Consequently, it and its southern extensions are modeled as barriers to horizontal ground-water flow (Plate IV).

Direct evidence bearing on the relative hydraulic conductivity of the O'Connor Fault is sparse. In their detailed study of streamflows and water chemistry in Eccles Creek and tributaries, Vaughn Hansen Associates (1979) found a significant increase in flows where streams crossed the O'Connor Fault. Water chemistry data also indicated changes where the streams cross the fault. These observations have been interpreted to suggest that the O'Connor Fault is relatively open and transmissive (Vaughn Hansen Associates, 1979; HCI, 2003). In fact, however, the discharge of ground water of deep-aquifer chemistry along the fault zone more strongly suggests up-welling against an aquaclude, and that the O'Connor is, at least in the Eccles Creek drainage, a barrier to horizontal ground-water flow. This interpretation is consistent with the large (600 ft) vertical displacement of the O'Connor Fault north of Electric Lake, and with a presumed broad damage zone along that portion of the fault. The O'Connor Fault south of Electric Lake shows only about 100 ft of vertical displacement. HCI assumes that along this portion of the fault the K is relatively high where the fault cuts sandstone units (Plate IV).

Although available evidence is somewhat ambiguous, the relative hydraulic conductivity of the Connelville Fault might be opposite to that of the O'Connor Fault. North of Electric Lake where vertical displacement is great on the O'Connor Fault, the vertical displacement on the Connelville Fault is as small as 200 ft. Along this reach of the fault Vaughn Hansen Associates, in the study described above (1979), found no indication of any up-welling of ground water where the Main or South Forks of Eccles Creek cross the Connelville Fault. This suggests that the Connelville Fault does not impede horizontal ground-water flow along its reach north of Electric Lake, and therefore might be a relatively conductive structure. Conversely, numerous encounters with the Connelville fault in the Skyline Mine have generated only a few hundred gpm of ground-water inflow. In the White Oak Mine and Belina No. 1 Mine (Figure 1), relatively large initial inflows at Connelville Fault crossings were found to decrease rapidly over short periods of time (DOGM, 2001; Vaughn Hansen Associates, 1979). These encounters suggest that the Connelville Fault might not be a highly-conductive structure.

Nevertheless, for the purpose of constructing a conservative model, HCI assumes that the Connelville Fault, where it cuts the deep units beneath and north of Electric Lake, is characterized by high K values (Plate IV). South of Electric Lake the vertical displacement of the

Connelville Fault increases greatly, to as much as 1,200 ft. For that reason, the horizontal hydraulic conductivity of the fault zone south of Electric Lake is assumed to be low.

Figure 10 shows the three intermediate-displacement interior faults, and the relative displacement and concomitant relative permeabilities along their traces. The hydraulic properties of all faults used in the model are shown in Table 5.

3.3 HYDROLOGIC BOUNDARIES

The boundaries for the Skyline numerical model have been selected to coincide with natural hydrologic boundaries to limit the amount of ground-water and surface-water flow that naturally enter and exit the HSA. The eastern and western boundaries (Plate IV) are defined by the Pleasant Valley and Gooseberry Faults, respectively. As previously described, both of these regional faults juxtapose the Starpoint sandstones against thick sequences of much lower permeability siltstones and shales. The northern boundary of the model limit is the south fault of the Fish Creek graben, currently assumed to be located in Fish Creek Canyon. All of these boundaries are assumed to be no-flow boundaries (i.e., there is no lateral inflow or outflow across them).

The southwestern model boundary is defined by a surface-water divide along the high ridge west of Joe's Valley and the divide below Paradise Creek Valley. It is assumed that the surface-water divide corresponds to a ground-water divide that also creates a no-flow ground-water condition. The southeastern model boundary follows the channel of Left Fork and is also assumed to be a no-flow boundary as a result of the Mancos shale (with very low hydraulic conductivity) being exposed in the creek bed along this reach. Scad Valley (in northeastern Joes Valley) is not included in the model, because it is hydrologically isolated from the model domain by the Valentine Fault and the outcropping of Mancos shale in Left Fork.

3.4 GROUND-WATER RECHARGE

Recharge to the ground-water system includes shallow-circulating ground water, which re-emerges in the surface-water system, and a much smaller component of deeply circulating ground water. Recharge to large hydrologic basins in the western U.S. is commonly estimated using the Maxey-Eakin method (Avon and Durbin, 1994). The Maxey-Eakin method assigns recharge coefficients (actually fractions of the yearly precipitation) to zones defined by rates of precipitation. In the HSA for the Skyline mine, however, all areas fall into just one Maxey-Eakin precipitation zone -- the zone representing upland recharge with greater than 20 inches of yearly precipitation. The Maxey-Eakin coefficient for this zone is 25 percent. Utilizing this factor in the Skyline model applies such a large volume of recharge in the HSA that the model could not be calibrated using any reasonable set of hydraulic properties. Zhu (2000), Greenslade (2000), and others have argued that the Maxey-Eakin method can greatly overestimate recharge in studies dominated by high elevation and areas of relatively high precipitation, particularly in areas such as the Skyline HSA where bedrock is predominant over alluvium. Consequently, HCI resorted to a more empirical method, somewhat similar to the Maxey-Eakin method, to estimate local ground-water recharge.

For this investigation, the volume of total recharge is assumed to be approximately equal to the volume of shallow recharge which in turn is assumed to be approximately equal to the volume of water that discharges to all of the streams in the HSA under baseflow conditions (the average October flow as described in Section 2.4). The recharge (in ft/yr) to the shallow ground-water system beneath each sub-basin in the HSA was calculated simply as the recorded baseflow (ft^3/yr) in the sub-basin divided by its area (ft^2) as planimetered on U.S. Geological Survey (USGS) topographic maps. By estimating the average elevation of each sub-basin (again, using USGS topographic maps), an orographic relationship was then developed to calculate ground-water recharge as a function of elevation (Figure 9). It should be noted that only four moderately sized sub-basins in the HSA were found to have long-term USGS streamflow data (Table 1). Some other streams in the HSA (e.g., Mud Creek, Fish Creek) have long-term flow data, but their basins encompass very large ranges in elevation. Unfortunately, several other important streams, including upper Huntington Creek and Left Fork, have insufficient gaging records; and they could not be used.

Linear regression analysis of the data shown in Figure 9 yields the relationship:

$$R = (0.00045 \cdot z) - 3.66 \tag{2}$$

where:

R = long-term average annual recharge to ground water (ft/year), and
z = average elevation of land surface (ft, NGVD).

This relationship can then be used to estimate recharge for areas with different elevations within the HSA.

For comparison, Maxey-Eakin recharge coefficients back-calculated from the results of this more local and empirical approach range from about 6 percent to about 15 percent for the four basins whose average elevations and annual precipitation range from about 8,400 ft and 24.3 inches to about 9,000 ft and 30.6 inches, respectively.

By virtue of the relatively high hydraulic conductivity assigned to the thin, uppermost layer in the model (described in Section 3.1.1), the majority of the shallow recharge calculated above is discharged to the local streams. A small component infiltrates downward to recharge the deeper ground-water system. The volume of this deeper recharge is a function of the vertical hydraulic conductivity of the lower overburden, and it was estimated during the steady-state calibration (described in Section 5.1).

4.0 DESCRIPTION OF NUMERICAL MODEL

4.1 NUMERICAL CODE USED IN STUDY

In this report the term "code" or "numerical code" is used to refer to a computer program that solves a system of equations that describe a ground-water flow problem. The term "model" or "numerical model" refers to a specific combination of a code, a finite-element mesh, hydrologic data, and boundary conditions that describe a specific set of site conditions. The term "numerical model" should not be confused with the previously described "conceptual hydrogeologic model" which is a qualitative description of the physical ground-water flow system simulated by the numerical model.

The numerical modeling described in this report utilizes the numerical code *MINEDW* that solves three-dimensional ground-water flow problems with an unconfined, or phreatic, surface using the finite element method (HCI, 1993). This code was developed and copyrighted by HCI (Timothy J. Durbin, P.E., was the primary author) to solve problems related to mine dewatering. Its special attributes specifically related to mine hydrology are described by Azrag et al. (1998). *MINEDW* has been validated by Sandia National Laboratories for the U.S. Bureau of Land Management as part of the EIS process for several gold mines in Nevada (Sandia National Laboratories, 1998).

4.2 MODEL GRID AND DISCRETIZATION

The current Skyline model domain encompasses approximately 140 mi^2, and the finite-element grid contains 32,172 nodes and 58,188 elements within 13 layers (Figures 10, 11, 12, and 13). The grid is most finely discretized in the area of the existing mine and Electrical Lake to:

- Refine numerical solutions of hydraulic heads and flows near the area of flow convergence, and

- More reasonably represent the geometry of the mine, location of the major ground-water inflows (Figure 14), and the location of pumping well JC-1.

The finite-element grid has also been discretized to incorporate the key hydrogeologic features of the HSA including the sandstone outcrops near the eastern boundary of the model, the location and orientation of the faults (Figure 14), and various surface-water bodies. In the detailed mine area, the minimum horizontal dimension of an element is in the range of about 600 to 800 ft (Figures10), and the thickness of layers ranges between approximately 10 and 900 ft (Figures 12 and 13).

4.3 MODEL BOUNDARIES

As introduced in Section 3.2, all of the model boundaries are assumed to be no-flow boundaries (Figure 10) as defined by:

1) The trace of the Gooseberry fault to the west. As described in Section 3.2, this fault zone is not explicitly incorporated into the model because of the great depth to the Starpoint sandstone in that area. The sandstone is the only unit that presumably would impart any significant hydraulic conductivity to the fault zone.

2) The Pleasant Valley fault to the east,

3) The southernmost Fish Creek fault to the north,

4) A topographic divide to the southwest, and

5) The Left Fork of Huntington Creek to the southeast.

Although they are no-flow boundaries to lateral flow, both the Pleasant Valley and Fish Creek faults are incorporated into the model as specific zones of enhanced vertical hydraulic conductivity that enable discharge from the deep aquifer system to the streams. Even though Fish Creek and the Left Fork of Huntington Creek coincide with no-flow boundaries, the streams themselves were simulated as drain nodes within the first layer of the model that enables ground-water discharge (to be described below).

The model is constructed such that all ground water within the model domain is generated by recharge from precipitation. Most of the recharge discharges back into the streams through the uppermost (assumed to be 150-ft thick) permeable portion of the Blackhawk Formation or sandstone layers where they crop out at the ground surface.

A small portion of the recharge reaches the deep aquifer system, especially at the southwestern part of the model, where:

a) The upper Starpoint sandstone is relatively close to the ground surface, and

b) Recharge from precipitation is relatively large due to high surface elevations.

Ground water within the deep system flows from south to north between the Gooseberry and Connelville faults (where it is tight) and between the Gooseberry and O'Conner faults where the Connelville fault is open. The deep ground-water system then discharges at the north-northeastern boundary where the Starpoint Sandstone is relatively close to the ground surface and there is a zone of enhanced vertical hydraulic conductivity associated with the Fish Creek and Pleasant Valley faults.

The bottom of the model is defined as the contact between the Starpoint Sandstone and the Mancos Shale with the exception of the bottom of Huntington and Left Fork Canyons, where the Mancos Shale is exposed at ground surface (Plate IV). This bottom boundary is defined as a no-flow boundary throughout the entire model domain.

4.4 SIMULATION OF HYDROLOGIC FEATURES

4.4.1 Simulation of Hydrogeology

In the finite-element method, hydraulic properties are assigned to elements; and hydraulic heads and fluxes are associated with nodes. Therefore, every element in the model is assigned to a model "zone" with specified values for horizontal (K_h) and vertical (K_z) hydraulic conductivity, specific storage, and specific yield (which is only utilized if the element contains the water table). There are 38 zones with different hydraulic parameters -- 14 for hydrogeologic units and 24 for faults -- incorporated into the model. The distribution of the 14 hydrogeologic units between 13 model layers and their relationship with the conceptual hydrostratigraphy is shown in Figure 8. The various hydrogeologic zones are shown in map view (for the uppermost layer) and in east-west and north-south cross-sections in Figures 11 through 13, respectively.

The hydraulic properties of the various hydrogeologic units in the model are summarized in Table 4. Some of the hydrogeologic units (e.g., the coals and the Storrs and Panther sandstones) are considered to be isotropic (i.e., $K_h = K_z$), but most of the sedimentary units have been made anisotropic with the general relationship $K_h > K_z$. This horizontal-to-vertical anisotropy is used to represent the effects of the interlayering of materials of higher and lower hydraulic conductivity.

4.4.2 Simulation of Faults

Ten faults are incorporated into the model (Figure 10) as discrete zones ranging from 100 to 400 ft wide:

1) Diagonal,
2) 14-Left,
3) 16-Left,
4) Connelville (northern and southern portions),

5) O'Connor (northern and southern portions),
6) Valentine,
7) Gooseberry South,
8) Fish Creek,
9) Pleasant Valley, and
10) West Mains.

The fault elements adjacent to the overburden and any other materials above the LOB seam -- referred to as the "upper part" -- are simulated with a relatively very low hydraulic conductivity with the general relationship $10K_h = K_z$ with the exception of the Fish Creek and Pleasant Valley faults, which are open within the overburden to allow all ground water at the northern boundary to discharge to Fish Creek and tributaries of Mud Creek. As explained in Section 3.2, the fault elements adjacent to all units below the top of the LOB seam (the coal, the interburden, and the sandstones) -- referred to as the "lower part" -- are simulated differently depending on the magnitude of displacement on the fault. The intermediate-displacement faults within the model domain are simulated with very low hydraulic conductivities in both the upper and lower parts. However, the small-displacement faults within the model domain are assumed to be highly conductive where they cut relatively brittle sandstone and coal (lower part), but essentially non-conductive where they cut more plastic, fine-grained sedimentary units. The hydraulic properties of the various faults simulated in the model are summarized in Table 5.

The 10-Left fault, which produces the largest inflow where it is intersected by mining within the LOB, is possibly a splay of the Diagonal fault; but in any case, it is not well-defined hydrogeologically. This fault appears to be relatively well connected to the Diagonal Fault further to the south along the fault plane (based on the response of piezometer 9-Left corehole), but not so to the Diagonal Fault immediately to the west, laterally through the Storrs and Panther Formations (Figure 14). This complex stratigraphic/structural relationship is further demonstrated by the fact that pumping from well JC-1, which is completed into the Storrs Sandstone within or immediately adjacent to the Diagonal Fault, has not had a major effect on reducing the inflow at 10-Left. These conditions were simulated in the model using the *FAULT* subroutine of *MINEDW* that links individual nodes with a high transmissivity. In this case, the five nodes simulating the LOB along the 10-Left fault were "fault-linked" vertically to the underlying Starpoint sandstones, and then five vertical columns were linked horizontally between each other and to the Diagonal fault to the south.

As will be discussed further in Section 4.6, fault linking was also used to simulate the three inflows at 11-Left-x24, 11-Left-x40, 11-Left-SU, and East Mains by a single node column.

4.4.3 Simulation of Recharge

Recharge to the ground-water system from precipitation was applied to each element on the top layer of the model by using the empirical relationship between recharge and surface elevation described in Section 3.5.

In both the steady-state and transient modes, long-term average precipitation was simulated (i.e., precipitation was not varied with time to reflect either seasonal or longer-term variations). Initially, time-variable recharge had been used for the transient calibration using actual monthly historical precipitation for each monthly time step in the model. However, those simulations showed that model-calculated gains and losses in Electric Lake attributable to variations in precipitation were great enough to mask any possible small losses attributable to mining. Hence, this "noise" in the model predictions was removed by using long-term average precipitation.

4.4.4 Simulation of Surface-Water Bodies

The streams, reservoirs, and springs were incorporated into the ground-water flow model. Streams and springs in the HSA are simulated using drain nodes along the courses of the streams with discharge calculated from the relationships:

$$Q = C_L \left(H_s - H_c\right) \quad if\ H_c > H_s \tag{3a}$$

or

$$Q = 0 \quad if\ H_c \leq H_s \tag{3b}$$

where

Q = ground-water discharge to the stream or spring (cfs),
H_S = specified elevation of stream (ft),
H_C = model-calculated elevation of water table (ft), and
C_L = leakance factor for the stream/spring node (ft^2/s).

The model incorporated 483 drain nodes to simulate Fish Creek, Mud Creek and Huntington Creek, and their numerous tributaries. Another 31 drain nodes were incorporated into the model to simulate springs along the Starpoint Sandstone/Mancos Shale contact along Huntington and Left Fork Creeks in the areas where the Mancos Shale crops out at the ground surface.

The drain nodes for both the streams and springs were assigned elevations based on the USGS topographic maps of the area. The fluxes from these drain nodes (calculated by either Equation 3a or 3b) are then summed to obtain a value for ground-water discharges to the various streams that can be compared to the measured baseflow data. As indicated in Equation 3b, the drain nodes streams and springs, which can only discharge from the ground-water system, are "turned off" when the calculated water table falls below their specified elevation.

Electric Lake is simulated in the model with constant-head nodes. The use of constant-head nodes instead of drain nodes allows the lake to gain ground water if the calculated water table in the adjacent formations exceeds the lake elevation and to lose water if the water table is below the lake elevation. Electric Lake was simulated with 52 such constant-head nodes. Initially, Electric Lake had been simulated in the model with variable (but still specified) head nodes reflecting historic lake-stage records. As with variable precipitation, the early transient calibration runs showed that water gains and losses attributable to the changing lake stage could significantly mask any possible small losses attributable to mining. Consequently, a long-term average lake stage of 8,560 ft was used in all further simulations.

4.5 SIMULATION OF MINING

Ground-water inflow induced by mining is simulated by assigning as drain nodes the nodes representing the bottom of the coal seam (either the UO or LOB) in the area being mined. Each drain node has a leakance factor calculated by:

$$C_L = \frac{K_m \cdot L \cdot w}{b} \tag{4}$$

where

K_m = hydraulic conductivity of material [m/day],
L = dimension of element [m],
w = width of area [m], and
b = thickness of "membrane" [m].

The value of K_m is an input value, L is a function of the grid discretization, and w/b (the so-called "connectivity factor") is a value obtained through transient calibration. Development of the three mining areas since 1982 was incorporated into the model with 391 such drain nodes. The calibrated connectivity factor for the mining nodes was 0.003.

In the numerical simulations, the hydraulic conductivity of the approximately 100-ft thick subsidence zone above a mined panel was increased by a factor of 10 in appropriate time steps (as described in Section 3.0). The longwall operations have been represented by 481 elements in the model and are simulated on a yearly basis according to mine plans provided to HCI by CFC.

4.6 SIMULATION OF PUMPING AND MAJOR GROUND-WATER INFLOWS

Pumping from well JC-1 is simulated explicitly in the model by a pumping node located on the Diagonal Fault in the Panther Sandstone layer. It should be noted that JC-1 was actually completed into the Storrs Sandstone within or immediately adjacent to the Diagonal Fault. In the model, the relatively very large hydraulic conductivity (20 ft/day) in the fault zone puts the Storrs and Panther sandstones in direct hydraulic connection. Therefore, the pumping node has been assigned to the lower Panther Sandstone interval). During the predictive runs, the pumping node is converted to a constant head node when the calculated water level reaches the elevation of the top of the Panther sandstone. This numerical approach enables the reduction in the pumping rate of JC-1 due to dewatering of the deep ground-water system to be replicated.

Well JC-2 was not incorporated into the model due to its insignificant pumping rate and short duration of. Pumping from JC-3, which is simply removing water that has already flowed into the flooded underground workings in the 10-Left areas, has no significant effect on the calculations of ground-water inflow. Consequently JC-3 is also not simulated in the model.

The major ground-water inflows are all explicitly simulated by specific drain nodes. The 14-Left, 16-Left, and 10-Left inflows were simulated along the appropriate faults incorporated into the model (Figure 14). The East Mains, 11-Left-x24, 11-Left-x40, and 11-Left-SU inflows were simulated as discharges from four localized and separate faults that were incorporated into the model by single columns of "fault-linked" nodes with high transmissivity hydraulically connecting the LOB coal with Starpoint Sandstones. The calibrated connectivity factors (described by Equation 4) for each of these drain nodes are summarized in the following table: following:

Inflow	Connectivity Factor
14-Left	incrementally decreased from 20 to 0.4
16-Left	incrementally decreased from 2.5 to 0.1
10-Left	100
East Mains	3.5
11-Left-x24	0.7
11-Left-x40	0.9
11-Left-SU	0.5

It should be noted that to replicate the 14-Left and 16-Left inflows, their connectivity factors were decreased in time. The East Mains, 11-Left-x24, 11-Left-x40, and 11-Left-SU inflows were replicated reasonably well using constant connectivity factors.

To replicate the largest ground-water inflow, the 10-L inflow, the leakance factor defined by Equation 4 was slightly modified to:

$$C'_L = \frac{C_L}{\sqrt{\Delta h}} \tag{5}$$

where

C_L = leakance factor from Equation 4, and
Δh = magnitude of change in hydraulic head dynamically calculated by model.

Equation 5 is valid for large ground-water flows that are "throttled" by either non-Darcian flow or by convergence of flow to a small diameter drainhole or fracture that intersects this flow (Azrag et al., 1998). The model-calculated discharge at 10-Left was calibrated to the measured inflow by using Equation 5 with a connectivity factor of 100.

4.7 MODEL CALIBRATION

The model was calibrated first to steady-state (pre-mining) conditions and then to transient (i.e., time dependent) conditions. The steady-state calibration consisted of adjusting the model input data, primarily the recharge and hydraulic conductivity values, until the calculated ground-water elevations and ground-water discharges to streams reasonably replicated the known or assumed conditions prior to any major mining or pumping stresses. The water levels or hydraulic heads calculated in the steady-state calibration were then used as the initial heads for the subsequent transient calibration. During the transient calibration, the values of the model input data (especially the storage and hydraulic conductivity values) were then further refined until predicted water-level changes reasonably replicated measured water level changes resulting from the hydraulic stresses (e.g., pumping, mine inflows).

4.7.1 Steady-State Calibration

For the steady-state calibration of the model, the elevation-dependent long-term average recharge (described in Section 3.5) was applied to all elements at the top of the uppermost layer in the model. The primary criterion for steady-state calibration was the matching of modeled pre-mining water levels to measured values, and matching stream baseflows to measured or estimated values. Since there were no pre-mining measurements of water levels in much of the HSA, the more general criterion for steady-state calibration in much of the HSA was simple that the calculated water table should be below ground surface. The hydraulic properties of the thin uppermost layer were adjusted until these criteria were met. Figure 15 shows a comparison of modeled to limited measured pre-mining water levels in shallow and deep monitoring wells.

It should be noted that the hydraulic conductivity of the thin surface layer and the recharge comprise a non-unique combination to replicate the water table elevations and the baseflows of the various streams and springs. In the conceptual model, the thin uppermost layer represents a near-surface zone of weathered and broken rock whose thickness and hydraulic properties have not been measured and, even if they were, would be highly variable. The assumed hydraulic conductivity is then "coupled" with the assumed recharge to produce reasonable water levels and baseflows. HCI believes that the combination of hydraulic conductivity of the near-surface zone and recharge used in this investigation is quite reasonable.

An estimate of the recharge factor to the deep aquifer system was obtained during calibration of the model by varying the vertical hydraulic conductivity of the Blackhawk Formation layers in the model. Model simulations were run until measured average streamflows in each sub-basin were matched. The resulting vertical hydraulic conductivity of the upper model layers were used in all further modeling to ensure reasonable recharge to the deep ground-water system. The steady-state calibration also included adjusting the hydraulic properties of the sandstone units and the faults until a reasonable representation of deep ground-water levels and hydraulic gradients was obtained. The model-calculated pre-mining water levels in the upper Starpoint Formation derived by the steady-state calibration are shown in Figure 16.

The water budget, often alternatively referred to as the water balance or hydrologic budget, for the entire model domain at any instant in time can be described by the relationship:

$$\boldsymbol{I + R - Et \pm SW - O \pm \Delta S \approx 0} \qquad \textbf{(6)}$$

where

I = ground-water inflow,
R = recharge to ground-water system,
SW = net surface-water flow to/from ground-water system,
O = ground-water outflow, and
ΔS = change in ground-water storage.

The recharge (R) is assumed to be the remainder of precipitation less evapotranspiration and runoff. In the case of steady-state flow, ΔS is equal to zero. The values for the various components of the water budget obtained during the average, long-term, pre-mining ("steady-state") calibration of the Skyline model are shown in Table 6.

Table 7 is a comparison of modeled vs. measured and estimated stream baseflows. The volume of simulated ground-water discharge to surface streams cannot easily be calibrated to gaged baseflow of the streams. For example, the model-calculated value for Fish Creek of 6.9 cfs does not compare well with the long-term average measured value of 11.5 cfs until it is recognized that only about half of the Fish Creek drainage is represented in the model. Furthermore, the value for all of Huntington Creek as far as the Left Fork confluence (20.0 cfs) and the value for Left Fork (15.3 cfs) cannot be directly calibrated because reservoir operations make it impossible to gage baseflow in those streams. Based on the size and elevations of the two large basins and on long-term average October discharge from Electric Lake, the values in Table 7 appear to be reasonable.

The discharge to Mud Creek (12.5 cfs) calculated during steady-state calibration of the model also initially appears to be a poor replication. The baseflow of Mud Creek below Winter Quarters is only 7.3 cfs, but only about 80 percent of the drainage is represented in the model. The source of the large simulated discharge to Mud Creek is the deep aquifer system, discharging at outcrops of the Starpoint Sandstone and faults in lower Eccles Creek (3.4 cfs vs. a gaged 1.8 cfs), Winter Quarters Canyon (4.9 cfs vs. an estimated 1.9 cfs), and Woods and Green Canyons (2.4 cfs, combined, vs. an estimated 1.9 cfs). The model simulates discharge of deep ground water into these drainages as a result of fault-defined no-flow boundaries and the very simplified near-surface occurrences of the Starpoint Sandstone units. In reality, the structure and stratigraphy are much more complicated around Scofield Reservoir; and as discussed in Section 2.5.3, deep ground-water discharge is probably much more diffuse than can be simulated in a model. When the anomalous flows to Woods, Green, Eccles and Winter Quarters Creeks are factored out (Table 7), the remaining modeled discharges to Mud Creek calibrates well to the estimated and gaged baseflows.

4.7.2 Transient Calibration

In the transient calibration, the goal was to replicate the existing data on historic water level changes and mine inflows. For this step of the calibration, the average recharge (Section 4.3.3) was again applied to all elements at the top of the uppermost layer in the model. During the calibration process, the hydraulic properties of the various hydrogeologic units, the transmissivity of the various faults, and the connectivity factors for the drain nodes were adjusted until a reasonable representation of ground-water inflows and water levels was obtained.

A comparison of the results of the transient calibration of the model to the measured inflows to the Skyline Mine is shown in Figure 17, and Figure 18 provides a comparison of calibrated to measured water level changes in the various monitoring wells and piezometers. HCI believes this transient calibration reasonably matches the measured and computed ground-water flows and water level changes in the model area.

Table 6 includes the values of the simulated ground-water budget for mining conditions as of April 30, 2003.

The comparison of ground-water discharges to streams calculated during the transient calibration to gaged stream baseflows were similar and have the same limitations as described above under the steady-state calibration.

5.0 RESULTS OF MODELING

5.1 CURRENT CONDITIONS

Figures 19 and 20 show the model-calculated ground-water levels and drawdowns, respectively, in the upper Starpoint Formation (model layer 13, Figure 12) as of April 2003. The water levels shown in Figure 19 compare most favorably with the potentiometric surface interpreted from measured water level data shown in Figure 4.

The most significant finding of the model simulations is that it is possible to account for essentially 100 percent of the inflow to the Skyline Mine by depletion of storage in the deep ground-water system. In other words, no significant additional sources of water -- either shallow ground water or surface water -- are required to balance the amount of water removed from storage in the deep ground-water system and that has flowed into the Skyline since 1982.

The model indicates that before mining, about 5 cfs (about 2,200 gpm) flowed through the deep aquifer system between the Gooseberry and Connelville Faults from the recharge area southwest of Huntington Reservoir to the discharge area in and around Scofield Reservoir. As described above, fault-defined no-flow boundaries and near-surface and surface exposures of the Starpoint sandstones result in discharge of ground water in Woods Canyon, Eccles Creek, and Winter Quarters Canyon. Mine inflows and the pumping from JC-1 have had only a very small effect on this throughflow, reducing it by approximately 0.5 cfs (225 gpm) as indicated in Table 6 (the difference in the current pre-mining combined discharges to Mud Creek and Fish Creek).

Table 6 also indicates that the calculated impact to Electric Lake, defined as the sum of the difference in recharge to ground water from Electric Lake (pre-mining vs. current) and the difference in ground-water discharge to Upper Huntington Creek and Electric (again, pre-mining vs. current) is 0.2 cfs (90 gpm).

A sensitivity analysis was conducted to evaluate a range of factors that might result in model calculations of greater inflow from Electric Lake into the mine workings. The first part of the sensitivity analysis evaluated the hydraulic conductivity of the Blackhawk Formation. It was found that no reasonable values for the hydraulic conductivity of the Blackhawk Formation could cause any measurable flow of surface water downward into the mine. Using values of hydraulic conductivity much higher than in the model resulted in very poor calibration to the shallow monitoring well data.

The next factor evaluated was the vertical hydraulic conductivity of the Diagonal Fault beneath Electric Lake. Figure 21 shows the effects of incremental increases in the vertical hydraulic conductivity of the upper portion of the Diagonal Fault under the Electric Lake by four orders-of-magnitude from the model-calibrated value of 0.01 ft/day (Table 5). It should be noted that the hydraulic conductivity of the fault could not be increased in any portion of the fault other than between the lake and the mine -- an unusual constraint -- without causing significant, unmeasured drawdown in the Blackhawk Formation. The results of the sensitivity analysis shown in Figure 21 have to be judged in terms of the "reasonableness" (which is obviously subject to different opinions) of:

1) the Diagonal Fault only having enhanced hydraulic conductivity under Electric Lake and

2) hydraulic conductivity in a fault within relatively plastic rocks could be as high as those included in the sensitivity analysis.

5.2 PREDICTIVE SIMULATIONS

Additional numerical simulations were made to predict the rate at which mine inflows might change over time if left unmitigated. The simulations assumed that

a) mining would proceed into the Winter Quarters area as projected on currently available mine plans, and

b) pumping would continue from JC-1 at the current rate of 4,000 gpm.

It was found, however, that the model predicts a slight reduction in the pumping rate of JC-1 to 3,800 gpm after year 2011 when it is predicted that the water level in the well will reach the top elevation of the Panther formation.

Figure 22 summarizes the results of the predictive simulations under these assumptions. The total inflow to the Skyline mine from all sources is predicted to decrease significantly over 10 years to approximately 3,700 gpm including inflow of about 3,200 gpm from the seven major inflows. The predicted decrease is the result of depletion of storage in the deep aquifer system and the associated decrease in head differences between the top of the deep sandstones and the mine. It should also be noted that the predicted inflows are based on the additional assumption that the inflow to the mine would continue to be pumped out into Eccles Creek or, via JC-3, into Huntington Creek. If the inflow were allowed to pool, the resulting increased head in the pool would further decrease the inflow rates.

The predictive simulations also indicate that the mine inflows and continued JC-1 pumping will further decrease the natural ground-water discharges in the Scofield area in the future. The model predicts that such discharges will be about 17.2 cfs (7,700 gpm) in 2013, a decrease of 2.2 cfs (1,000 gpm) relative to the pre-mining rate.

6.0 CONCLUSIONS

The Skyline Mine model is a hydrogeologically-based ground-water flow model that is calibrated to existing data and incorporates reasonable hydrologic assumptions. The model has been used to investigate the interactions of surface water, ground water, and mining stresses in the vicinity of Skyline Mine. The primary conclusions of this investigation are:

1) The inflows to the Skyline Mine do not include a significant component of Electric Lake water. This conclusion of the model corroborates three other lines of evidence as summarized in the following table:

Basis of Estimate		**Amount (gpm)**	**Comments**
Ground-water flow model	base case	90	most-reasonable parameters
	Sensitivity analysis	90-1,600	higher values based on unreasonable input values
Tritium analyses		1,200	"surface" water, though not necessarily from Electric Lake
Tracer tests		0	two Electric Lake-specific tests conducted by PacifiCorp
Temperature		no unique value	origin 600 to 1,000 ft deeper than mine

2) The ground-water flow model also corroborates early monitoring-well records showing that the pre-mining ground-water flow direction beneath the Skyline Mine was primarily to the north-northeast. Ground water in the sandstones exposed at the lower end of Electric Lake flowed both northeast and southeast away from the lake.

3) Mining-related stresses have not changed the overall flow directions. However, a localized drawdown cone has developed beneath the level 2 mine workings. Current drawdown exceeds 350 ft at the maximum point.

4) The model estimates that mining-related stresses currently cause a decrease in the discharge to Scofield Reservoir and its tributary streams of about 0.5 cfs (220 gpm) relative to the pre-mining discharge. The model predicts that this impact might increase to about 2.2 cfs (1,000 gpm) by 2013 (assuming continued pumping from JC-1, and continued pumping from the Skyline Mine).

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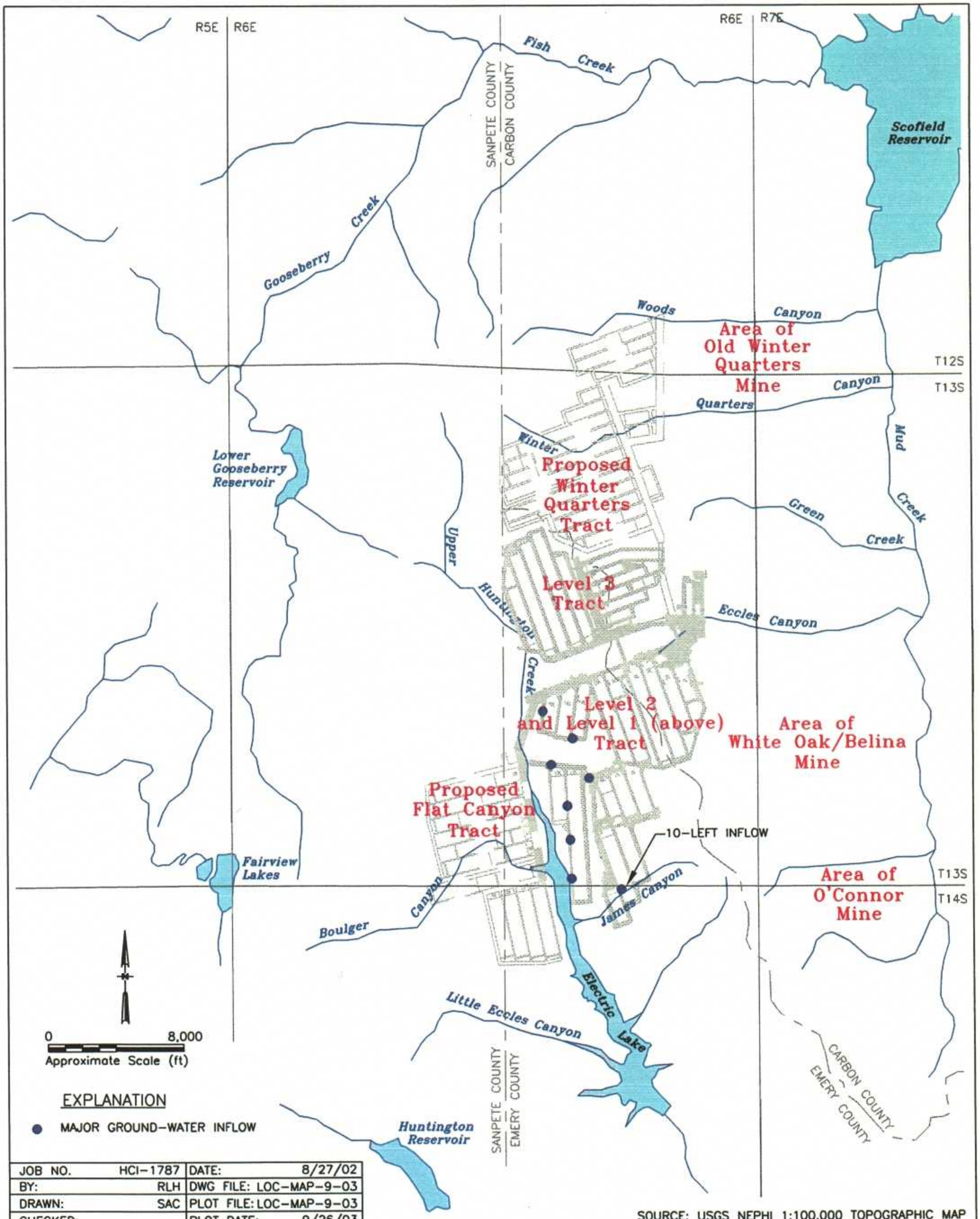

JOB NO.	HCI-1787	DATE:	8/27/02
BY:	RLH	DWG FILE:	LOC-MAP-9-03
DRAWN:	SAC	PLOT FILE:	LOC-MAP-9-03
CHECKED:		PLOT DATE:	9/26/03

SOURCE: USGS NEPHI 1:100,000 TOPOGRAPHIC MAP

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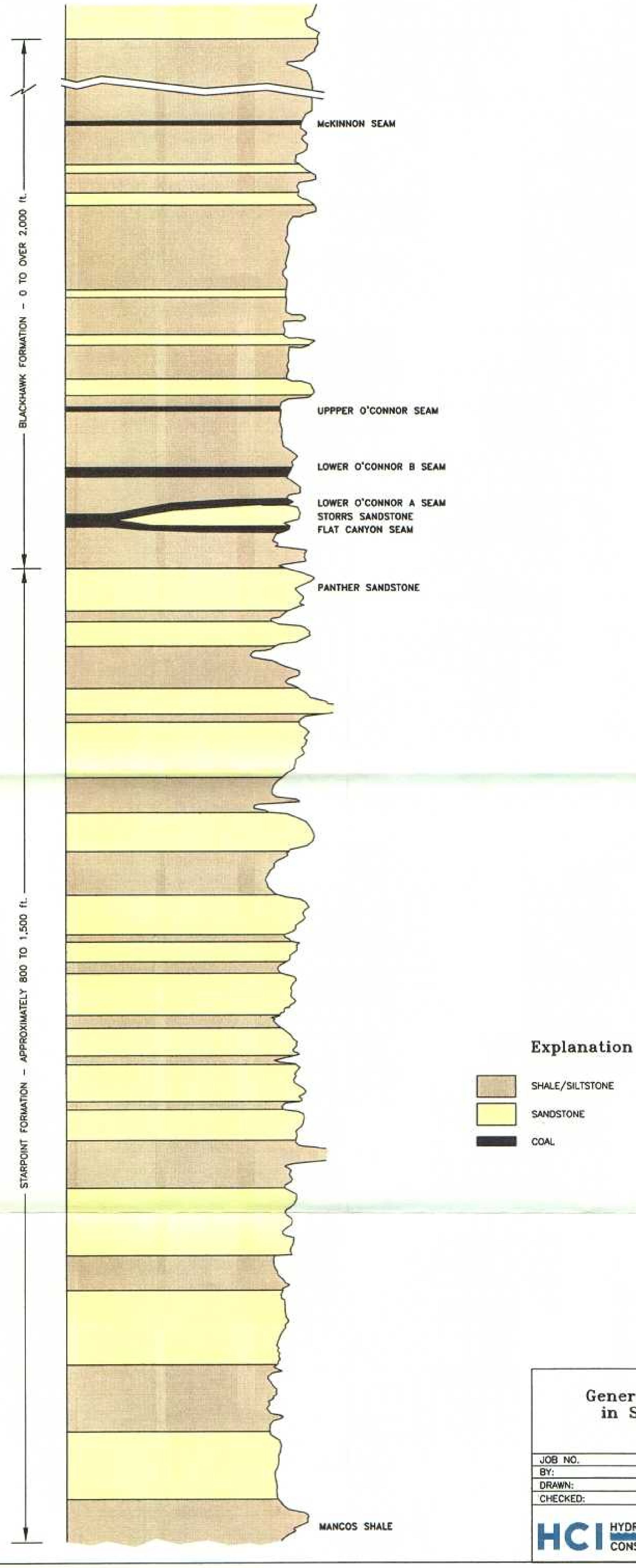
Base Map of Hydrogeologic Investigation

FIGURE 1



Generalized Stratigraphy in Skyline Mine Area

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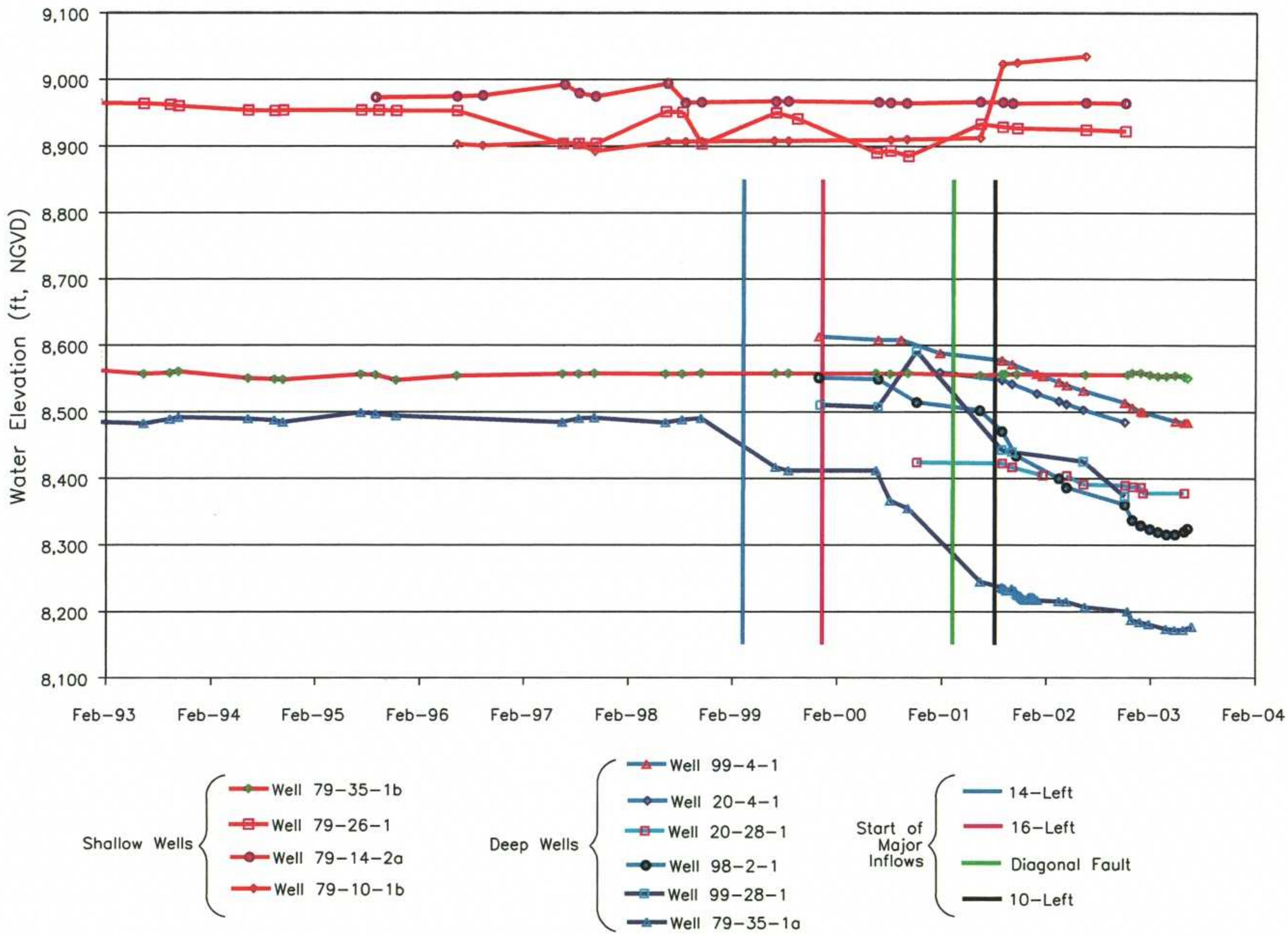
FIGURE 2



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BY:	RLH	DWG FILE:	WLVLS-DS
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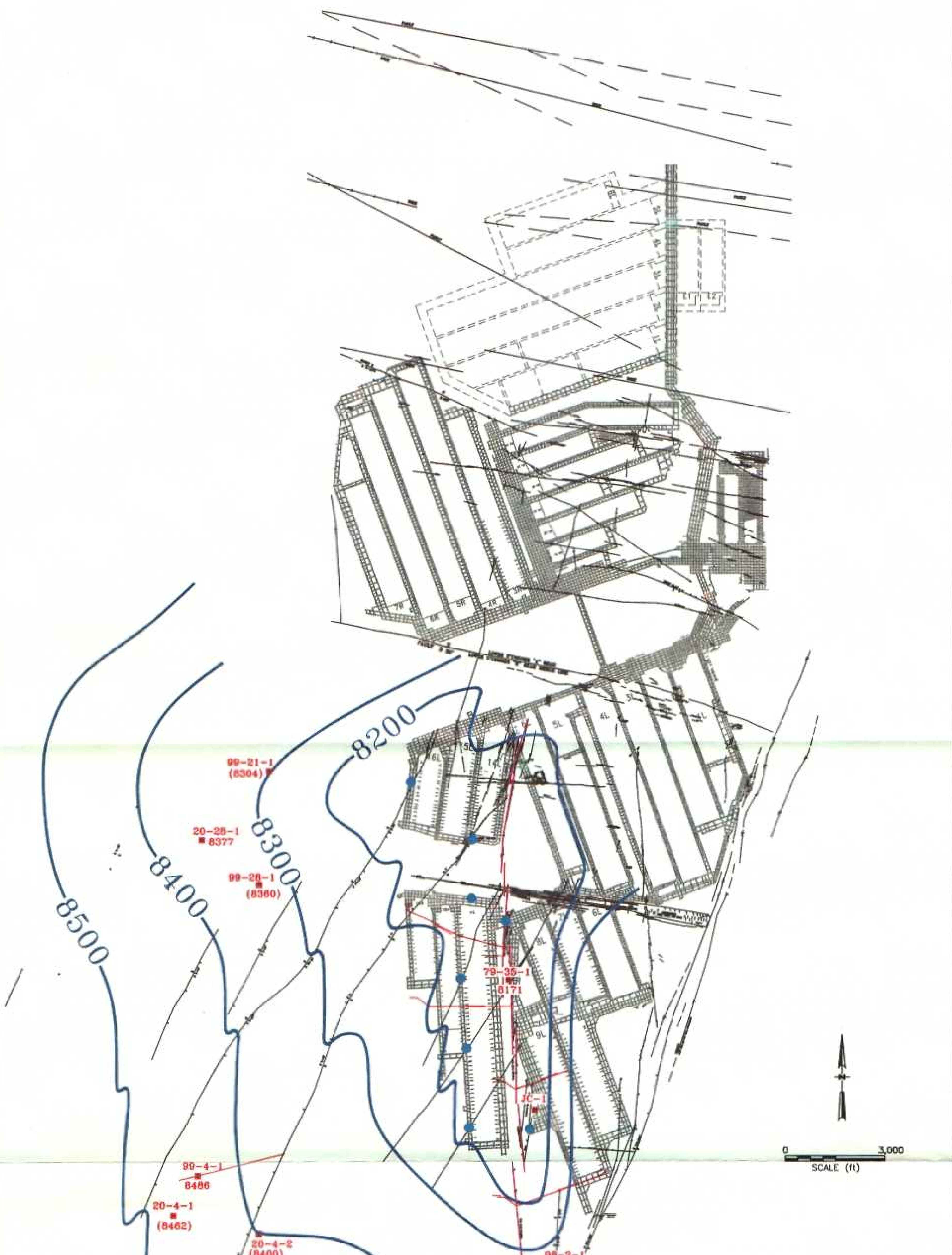
Water Levels in Deep and Shallow Wells

FIGURE 3



Measured and Estimated Water Levels as of April 2003

JOB NO.	HCI-1787	DATE:	12/12/01
BY:	RLH	DWG FILE:	INT-POT-LEVELS
DRAWN:	SAC	PLOT FILE:	INT-POT-LEVELS
CHECKED:		PLOT DATE:	10/2/03

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FIGURE 4

EXPLANATION

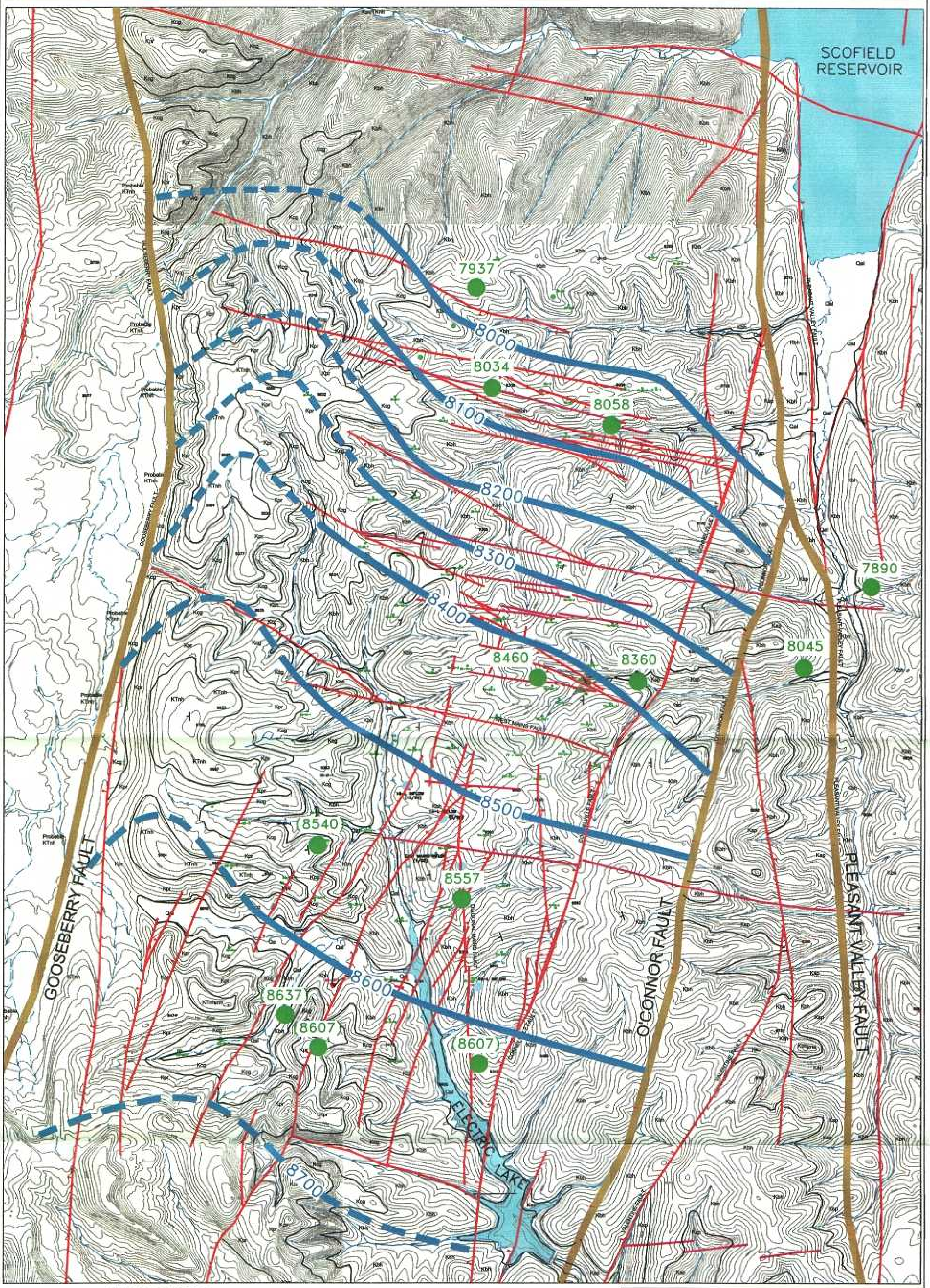
WATER LEVEL CONTOUR (ft, NGVD)

MAJOR INFLOW

DIAGONAL FAULT

20-4-1 8484 MONITORING WELL MEASURED WATER LEVEL

20-4-2 (8419) MONITORING WELL ESTIMATED WATER LEVEL



EXPLANATION

ESTIMATED PRE-MINING WATER TABLE CONTOUR (ft) (DASHED WHERE INFERRED)

FAULT

DIKE

8557 PRE-MINING WATER LEVEL

(8540) POST-MINING WATER LEVEL MEASUREMENT PROJECTED TO PRE-MINING LEVEL

N

0 5,000
SCALE (ft)

Measured and Estimated Pre-Mining Water Levels in Deep Aquifer Beneath Skyline Mine

JOB NO.	HCI-1787	DATE:	9/26/03
BY:	RLH	DWG FILE:	PREMINE-WL
DRAWN:	SAC	PLOT FILE:	PREMINE-WL
CHECKED:		PLOT DATE:	9/26/03

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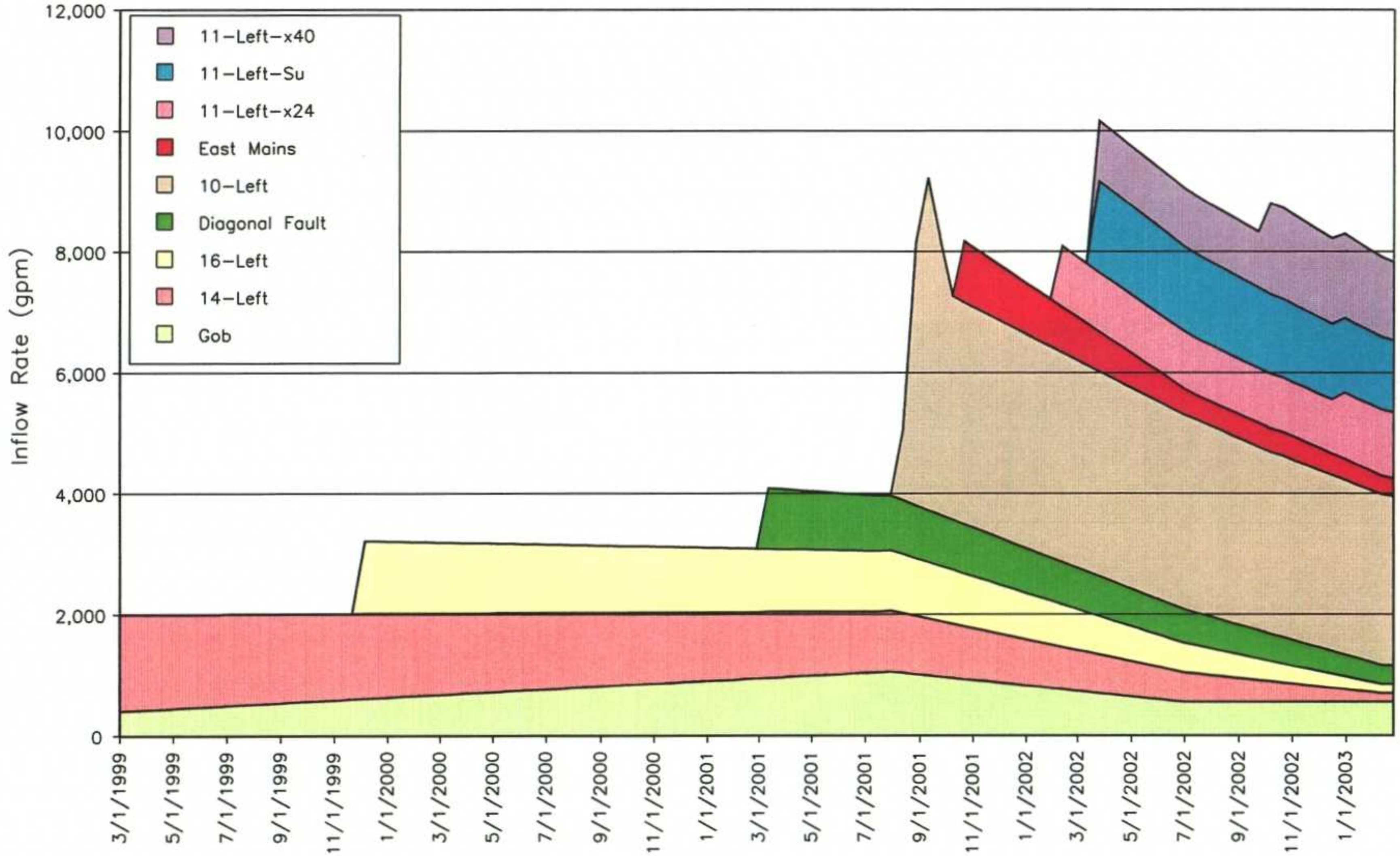
FIGURE
5



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JOB NO.	HCI-1787	DATE:	12/10/02
BY:	RLH	DWG FILE:	CGW-INFL
DRAWN:	SAC	PLOT FILE:	CGW-INFL
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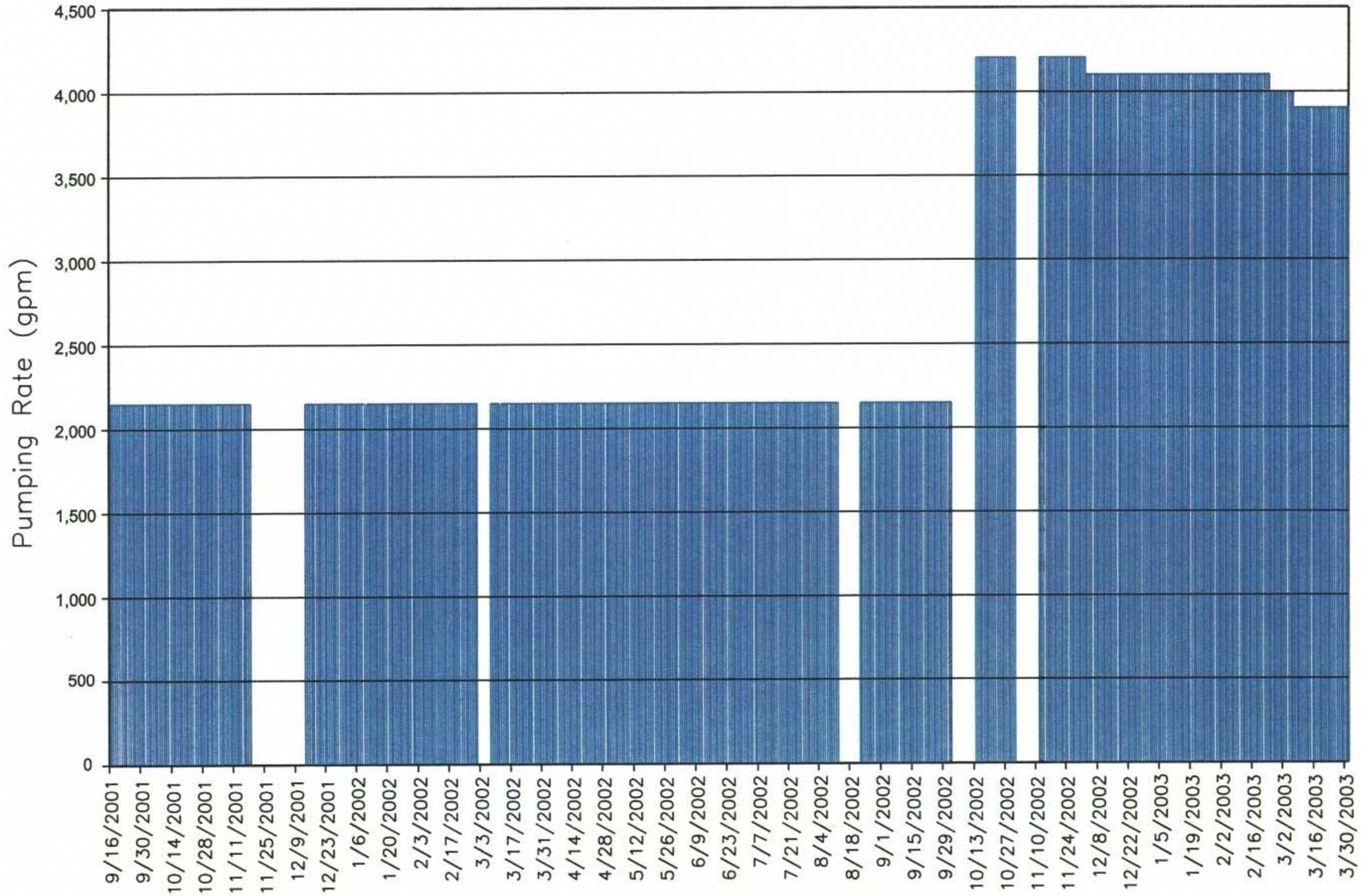
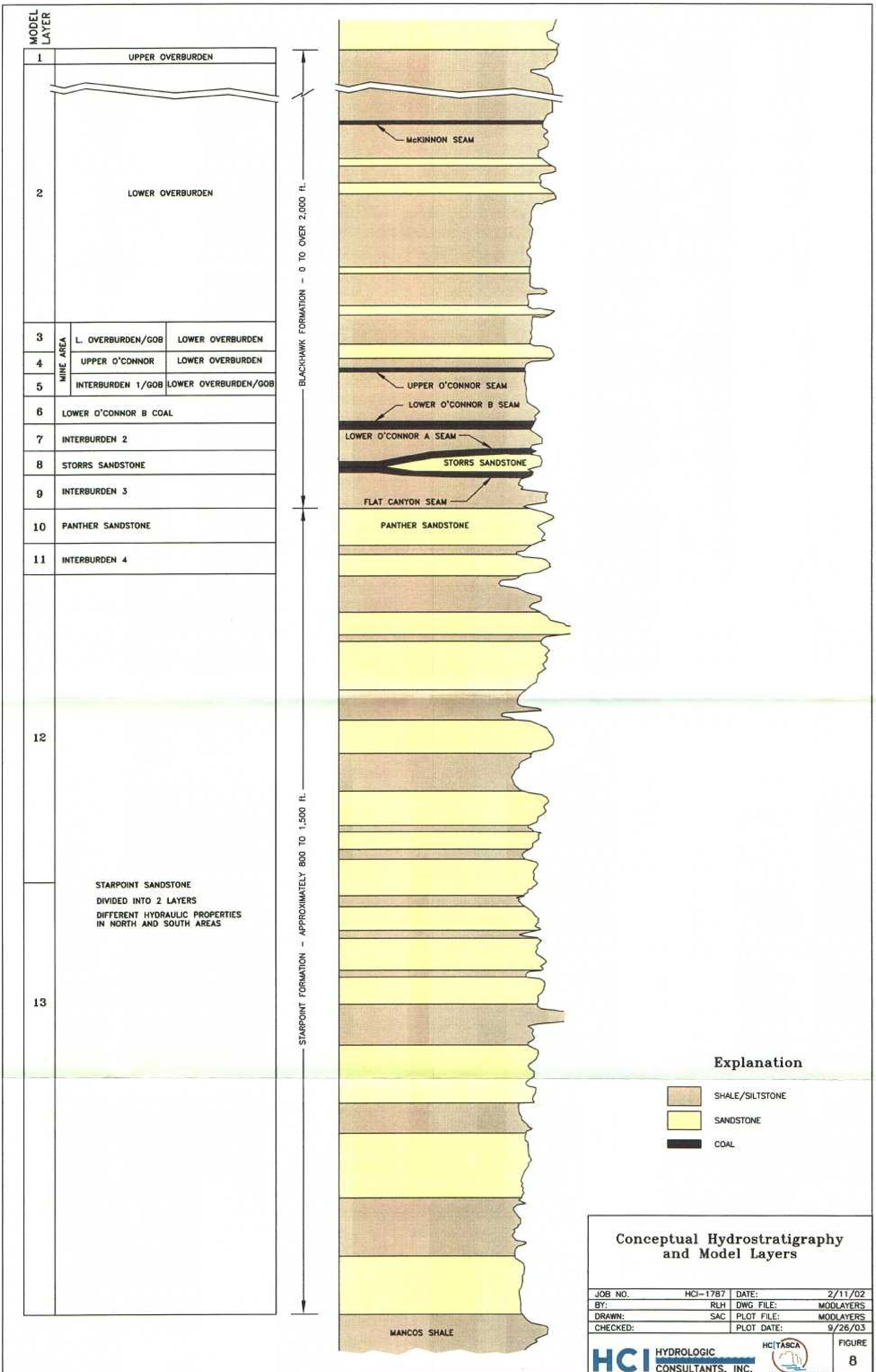
Cumulative Ground-Water Inflow to Skyline Level 2 Mine

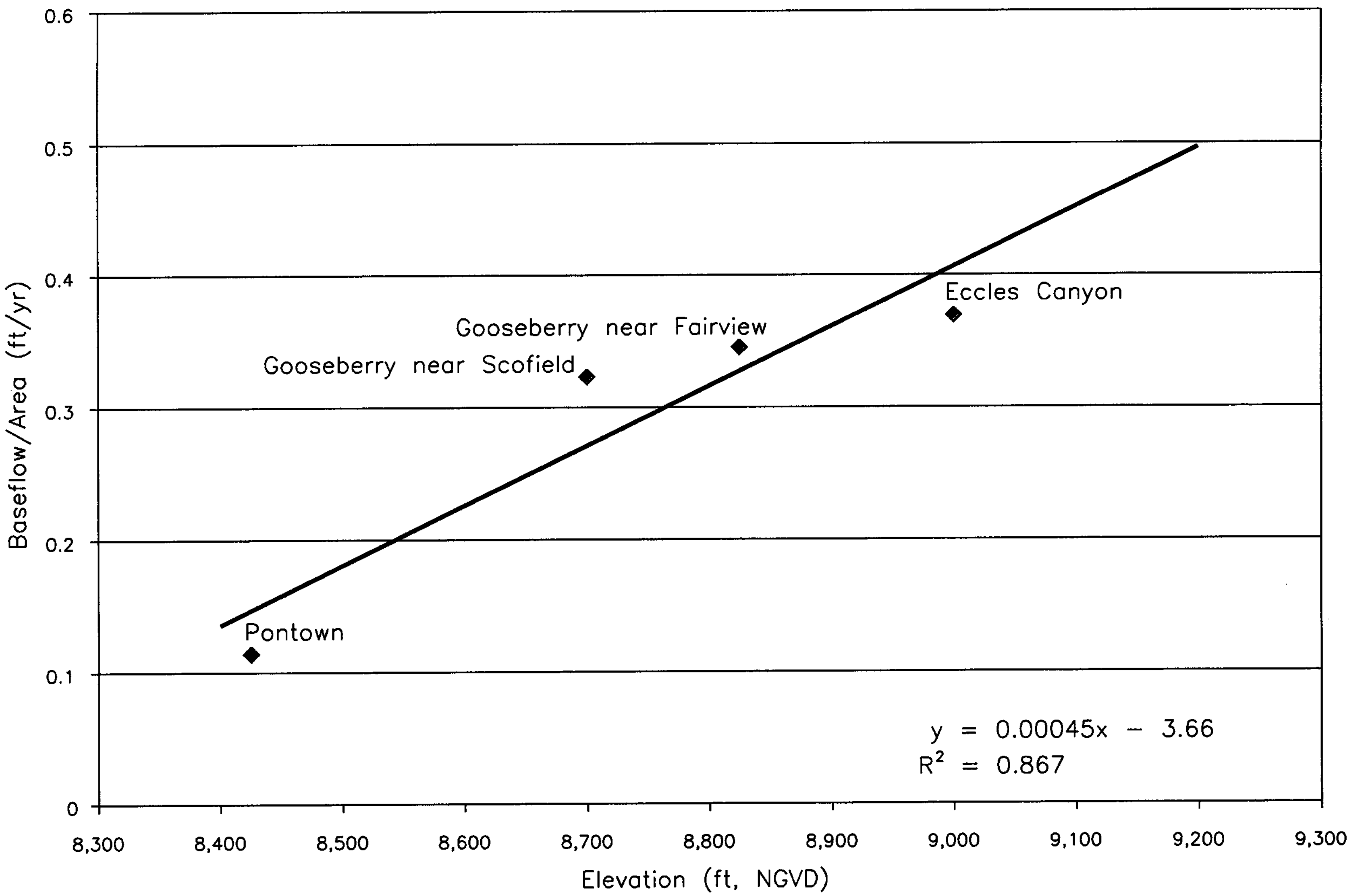
FIGURE 6



HCI HYDROLOGIC CONSULTANTS, INC. HCITASCA an company	JOB NO. HCI-1787	DATE: 12/12/02	Pumping from James Canyon Well JC-1	FIGURE 7
	BY: RLH	DWG FILE: PUMPSCHED		
	DRAWN: SAC	PLOT FILE: PUMPSCHED		
	CHECKED:	PLOT DATE: 9/26/03		



Conceptual Hydrostratigraphy and Model Layers



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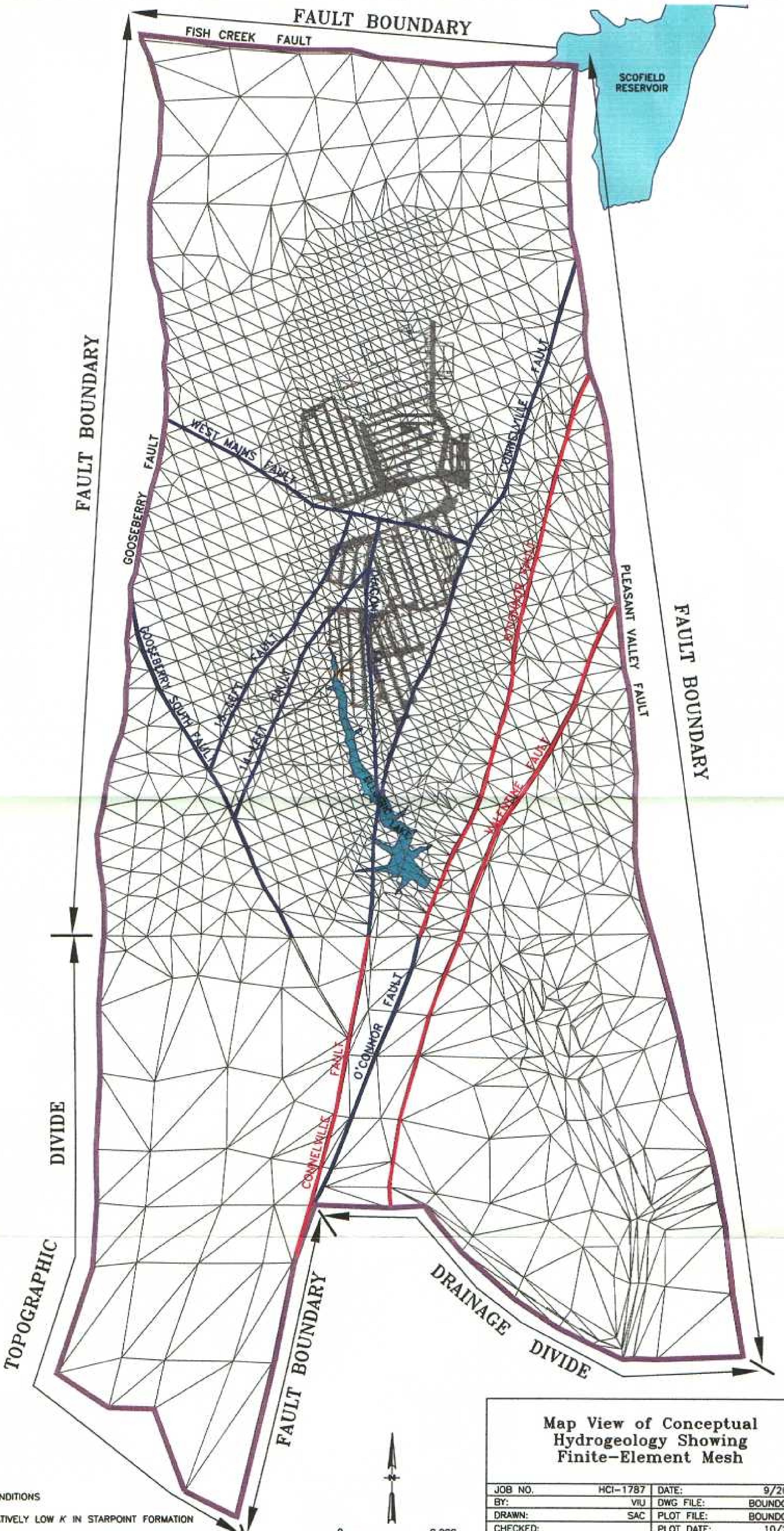
Elevation vs. Recharge in Moderate-Size Stream Basins

FIGURE 9



EXPLANATION

- NO-FLOW BOUNDARY CONDITIONS
- INTERIOR FAULT OF RELATIVELY LOW K IN STARPOINT FORMATION
- INTERIOR FAULT OF RELATIVELY HIGH K IN STARPOINT FORMATION

0 8,000
Scale (ft)

Map View of Conceptual Hydrogeology Showing Finite-Element Mesh

JOB NO.	HCI-1787	DATE:	9/26/03
BY:	VIU	DWG FILE:	BOUNDCOND
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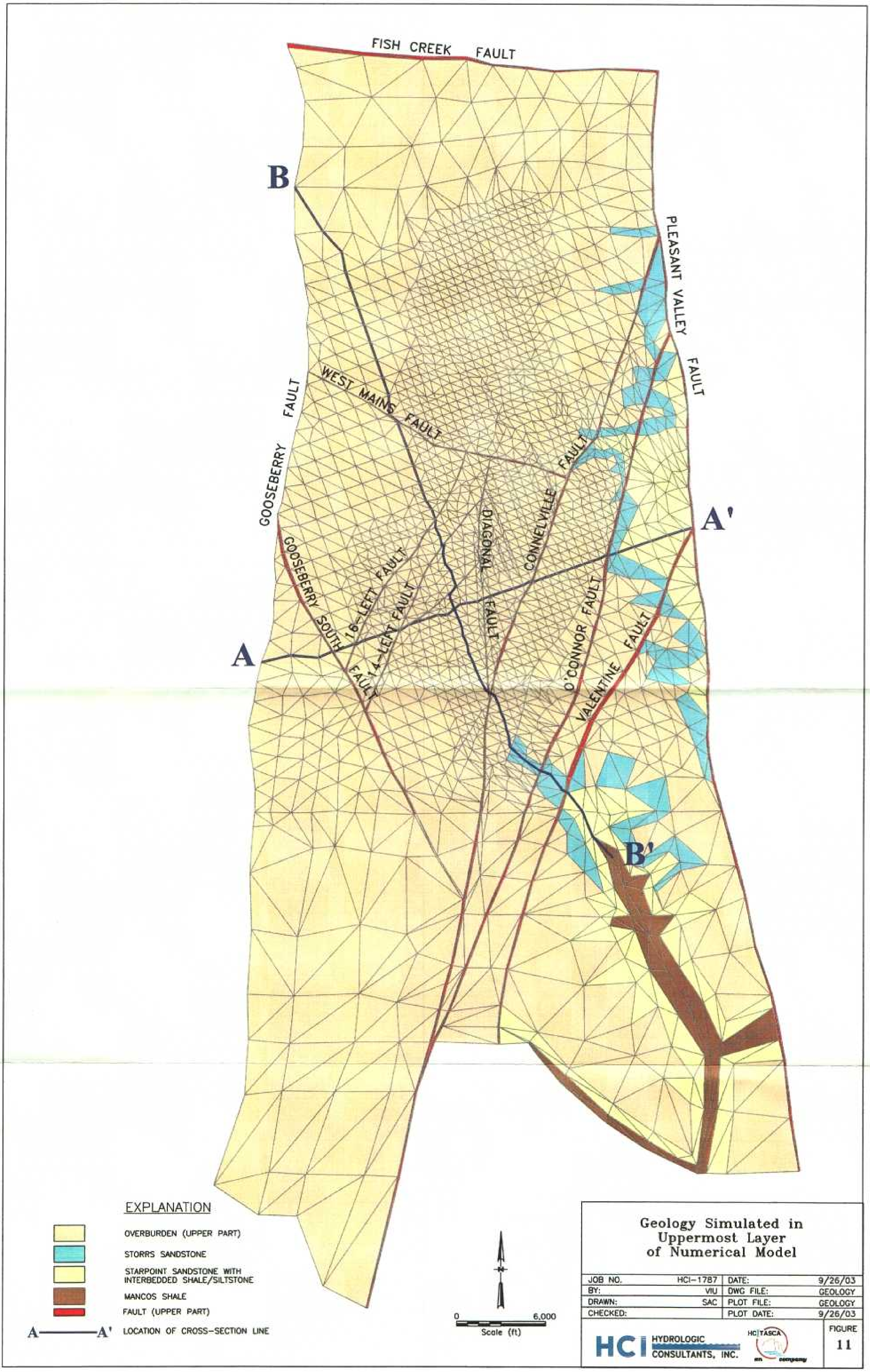
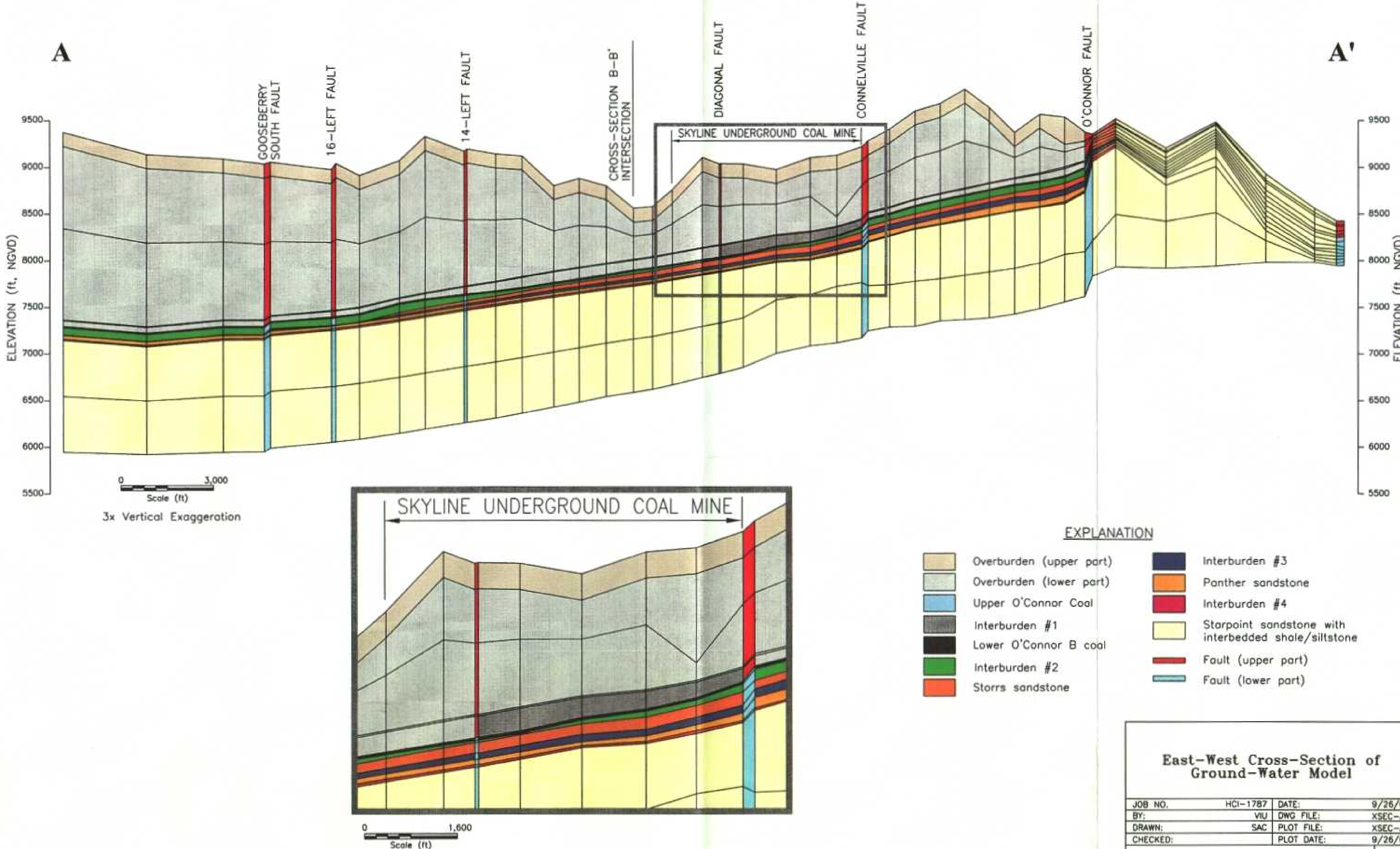
FIGURE 10


FISH CREEK FAULT
B
PLEASANT VALLEY FAULT
WEST MAINS FAULT
GOOSEBERRY FAULT
A'
CONNELVILLE FAULT
DIAGONAL FAULT
GOOSEBERRY SOUTH FAULT
16-LEFT FAULT
14-LEFT FAULT
A
O'CONNOR FAULT
VALENTINE FAULT
B'
EXPLANATION
OVERBURDEN (UPPER PART)
STORRS SANDSTONE
STARPOINT SANDSTONE WITH INTERBEDDED SHALE/SILTSTONE
MANCOS SHALE
FAULT (UPPER PART)
A——A' LOCATION OF CROSS-SECTION LINE
0
6,000
Scale (ft)
Geology Simulated in Uppermost Layer of Numerical Model
JOB NO. HCI-1787
DATE: 9/26/03
BY: VIU
DWG FILE: GEOLOGY
DRAWN: SAC
PLOT FILE: GEOLOGY
CHECKED:
PLOT DATE: 9/26/03
FIGURE 11
HCI HYDROLOGIC CONSULTANTS, INC.
HC|TASCA



East-West Cross-Section of Ground-Water Model

JOB NO.	HCI-1787	DATE:	9/26/03
BY:	VIU	DWG FILE:	XSEC-AA
DRAWN:	SAC	PLOT FILE:	XSEC-AA
CHECKED:		PLOT DATE:	9/26/03

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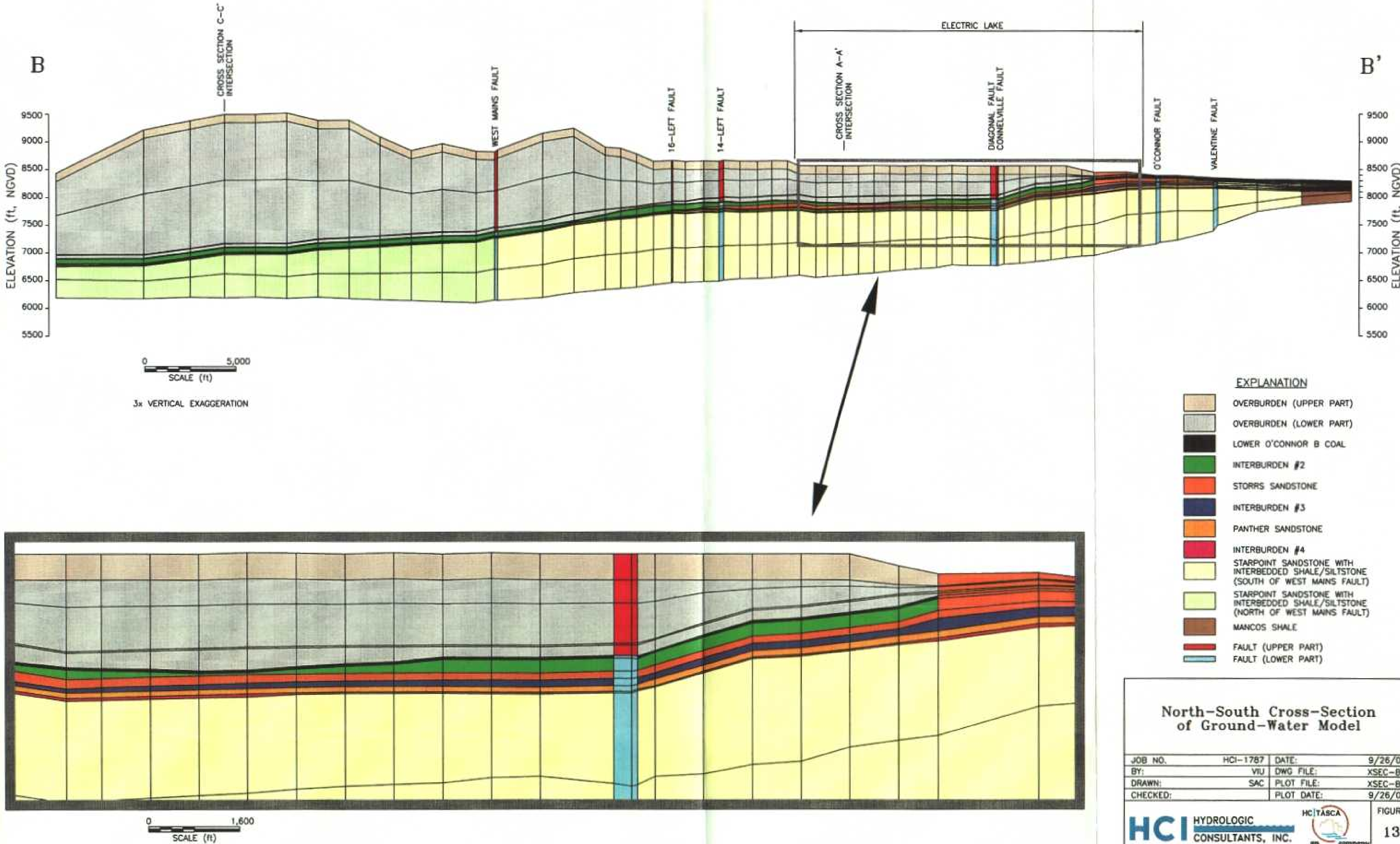
FIGURE 12



North-South Cross-Section of Ground-Water Model

JOB NO.	HCI-1787	DATE:	9/26/03
BY:	VIU	DWG FILE:	XSEC-BB
DRAWN:	SAC	PLOT FILE:	XSEC-BB
CHECKED:		PLOT DATE:	9/26/03

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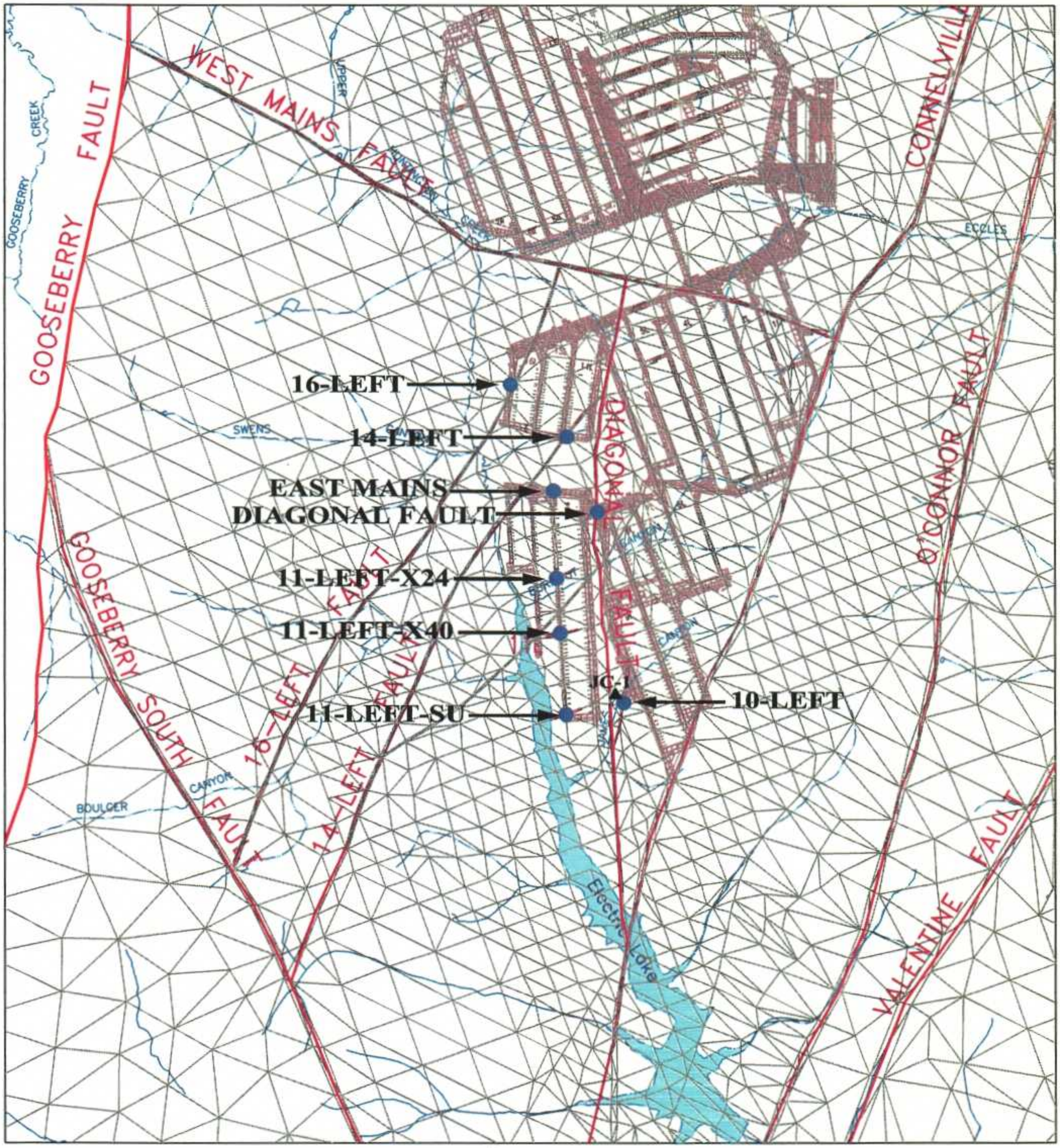
FIGURE 13



N

0 5,000
Scale (ft)

EXPLANATION

- MAJOR GROUND-WATER INFLOW
- FAULT SIMULATED IN MODEL
- MODEL BOUNDARY
- JC-1 PUMPING WELL

JOB NO.	HCI-1787	DATE:	9/26/03
BY:	VIU	DWG FILE:	LOC-INFLOWS
DRAWN:	SAC	PLOT FILE:	LOC-INFLOWS
CHECKED:		PLOT DATE:	10/2/03

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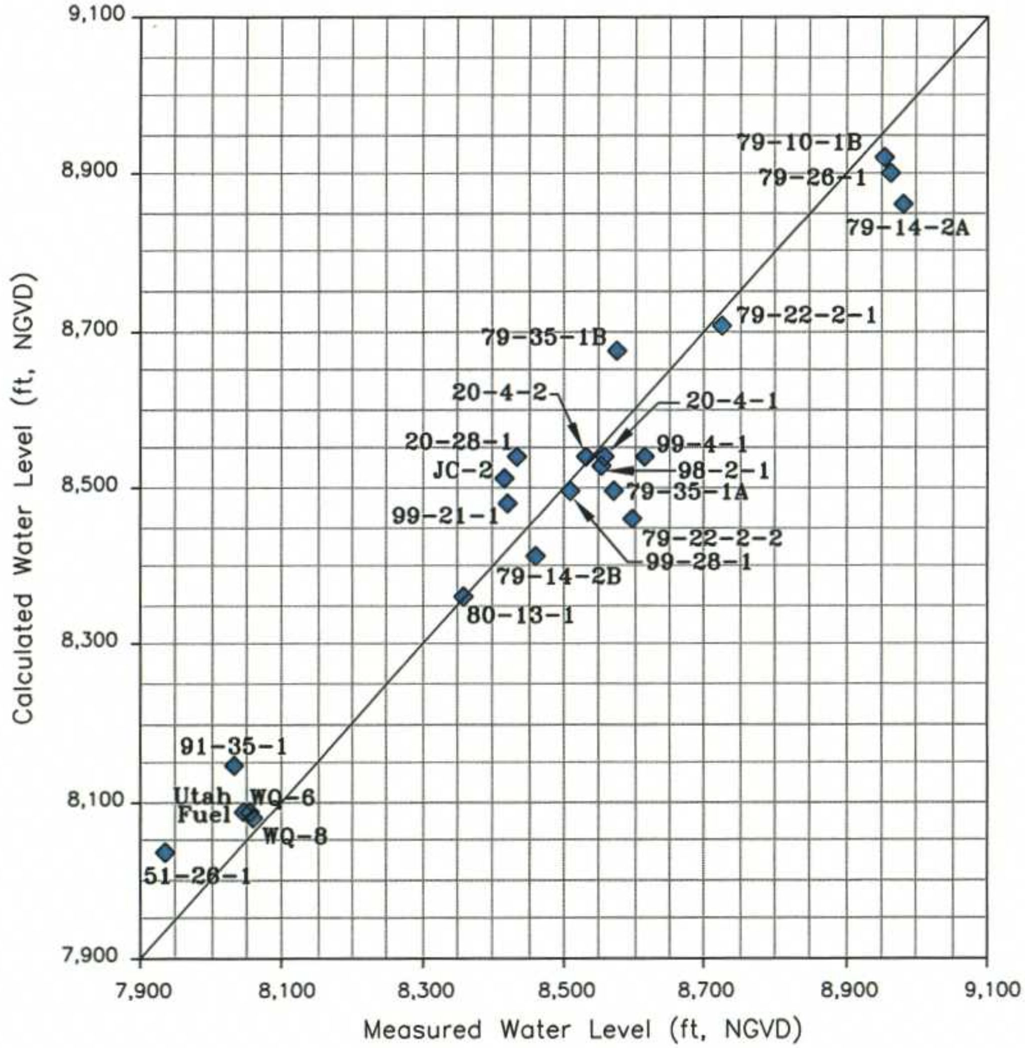
Simulated Locations of Faults and Major Ground-Water Inflows in Model

FIGURE 14

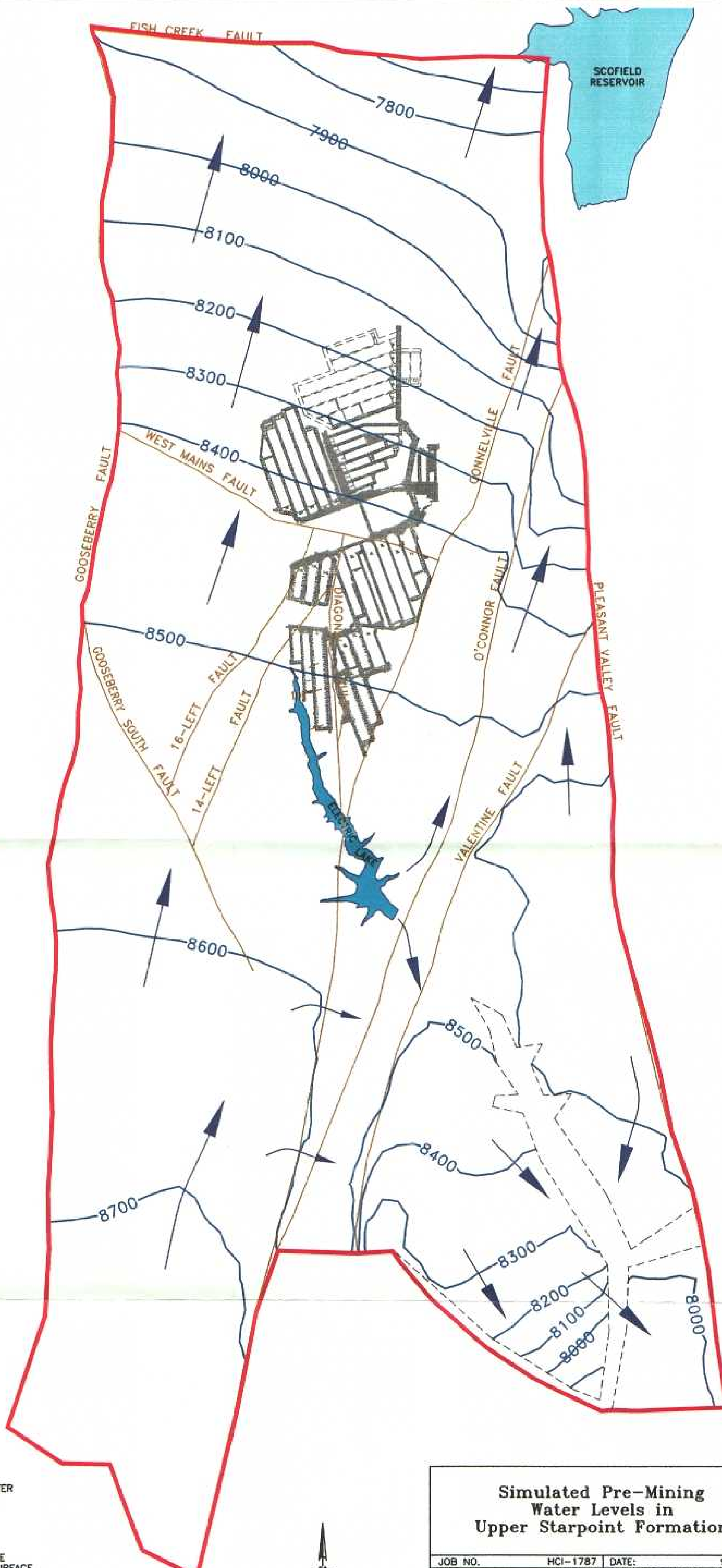


JOB NO. HCI-1787	DATE: 9/26/03		
BY: VIU	DWG FILE: CALIB		
DRAWN: SAC	PLOT FILE: CALIB		
CHECKED:	PLOT DATE: 9/26/03		

HCI HYDROLOGIC CONSULTANTS, INC. — HC|TASCA an company

Comparison of Modeled to Measured Pre-Mining Water Levels in Monitoring Wells

FIGURE 15



EXPLANATION

- SIMULATED PRE-MINING WATER LEVEL CONTOUR (ft, NGVD)
- MODEL BOUNDARY
- FAULT
- AREA WHERE MANCOS SHALE IS EXPOSED AT GROUND SURFACE
- DIRECTION OF GROUND-WATER FLOW

0 8,000
SCALE (ft)

Simulated Pre-Mining Water Levels in Upper Starpoint Formation

JOB NO.	HCI-1787	DATE:	9/26/03
BY:	RLH/VIU	DWG FILE: SIM-PRE-MINING-WL	
DRAWN:	SAC	PLOT FILE: SIM-PRE-MINING-WL	
CHECKED:		PLOT DATE:	10/2/03

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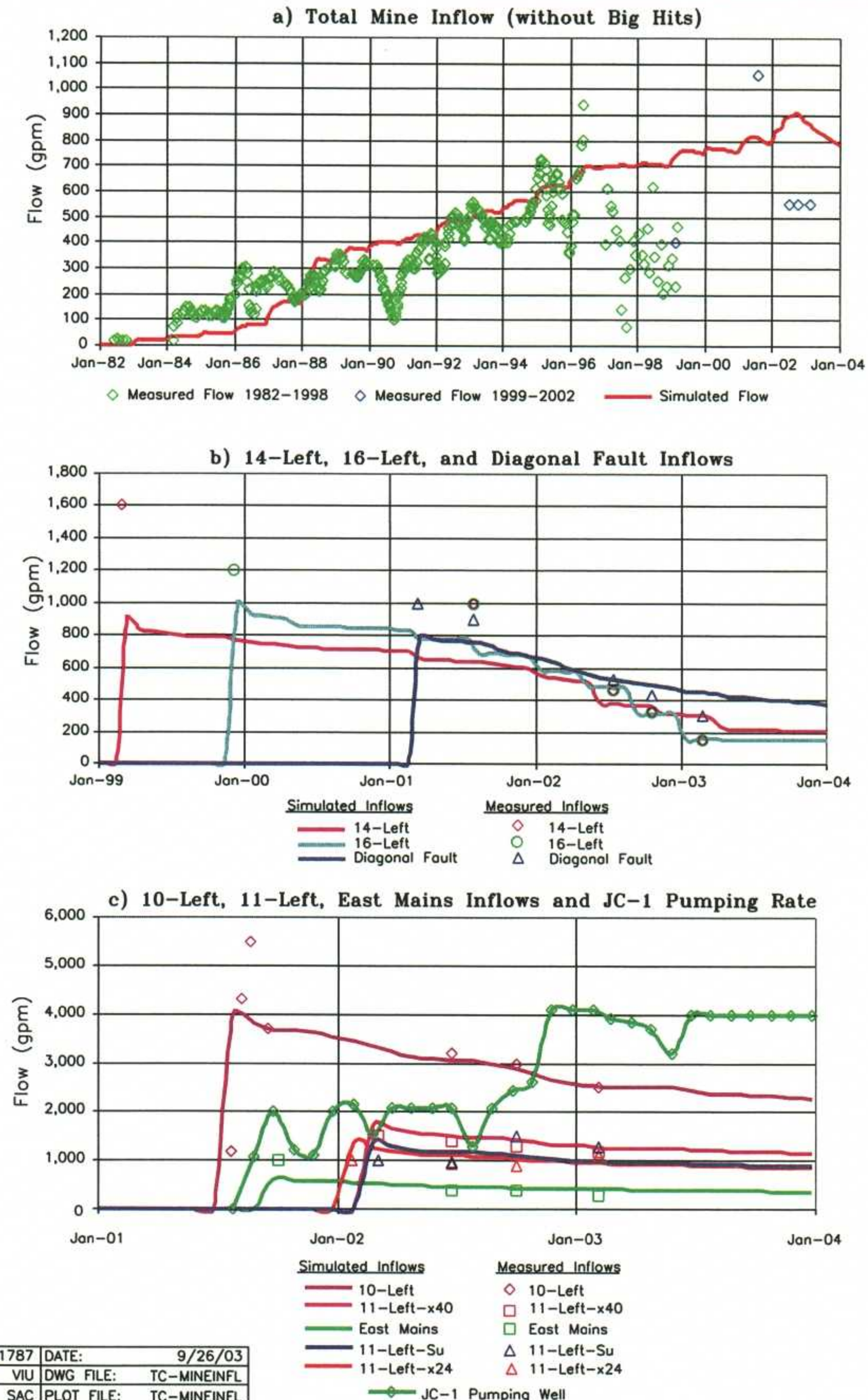
FIGURE 16



JOB NO.	HCI-1787	DATE:	9/26/03
BY:	VIU	DWG FILE:	TC-MINEINFL
DRAWN:	SAC	PLOT FILE:	TC-MINEINFL
CHECKED:		PLOT DATE:	9/26/03

HCI HYDROLOGIC CONSULTANTS, INC.

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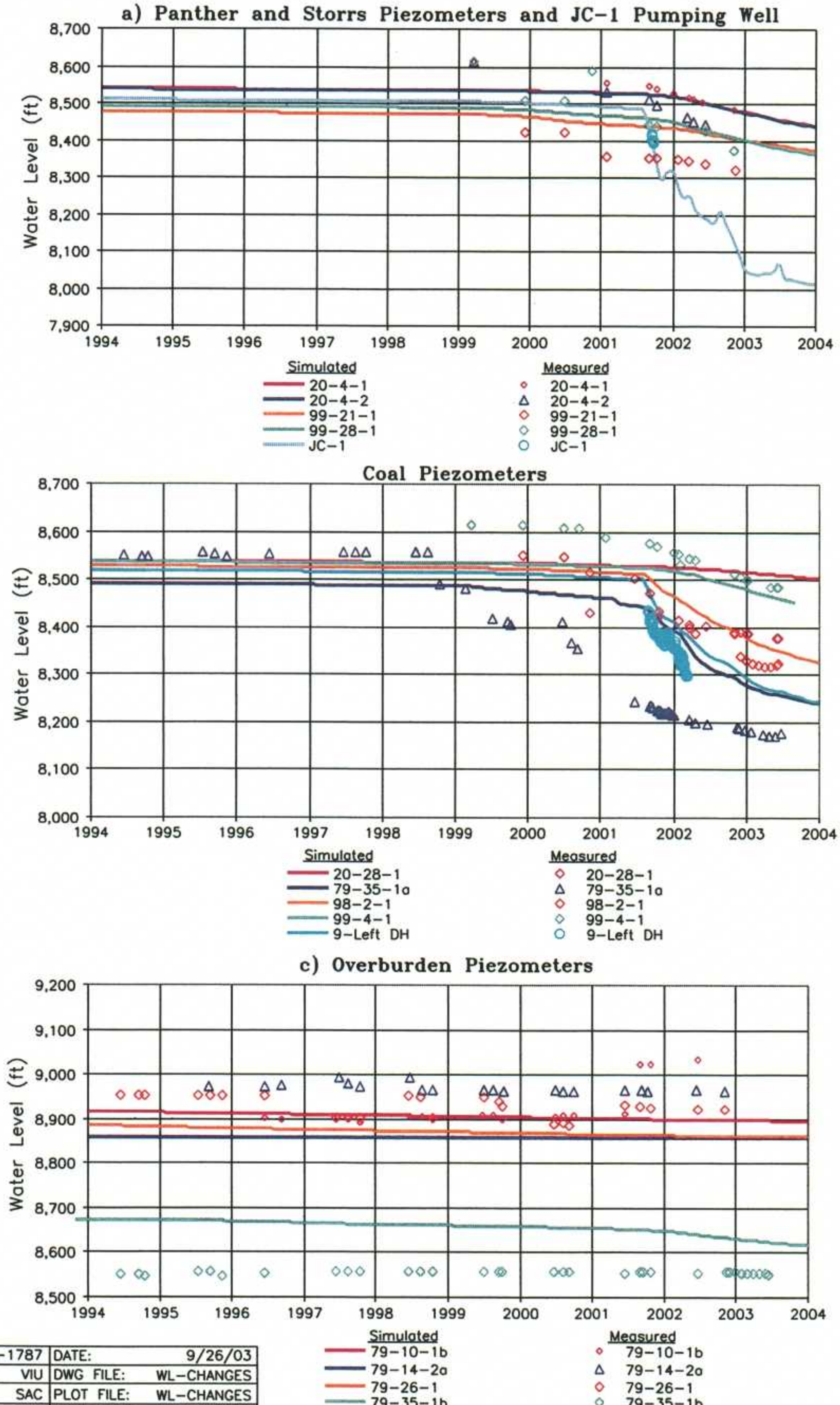
Comparison of Modeled to Measured Inflow Rates to Skyline Mine

FIGURE 17

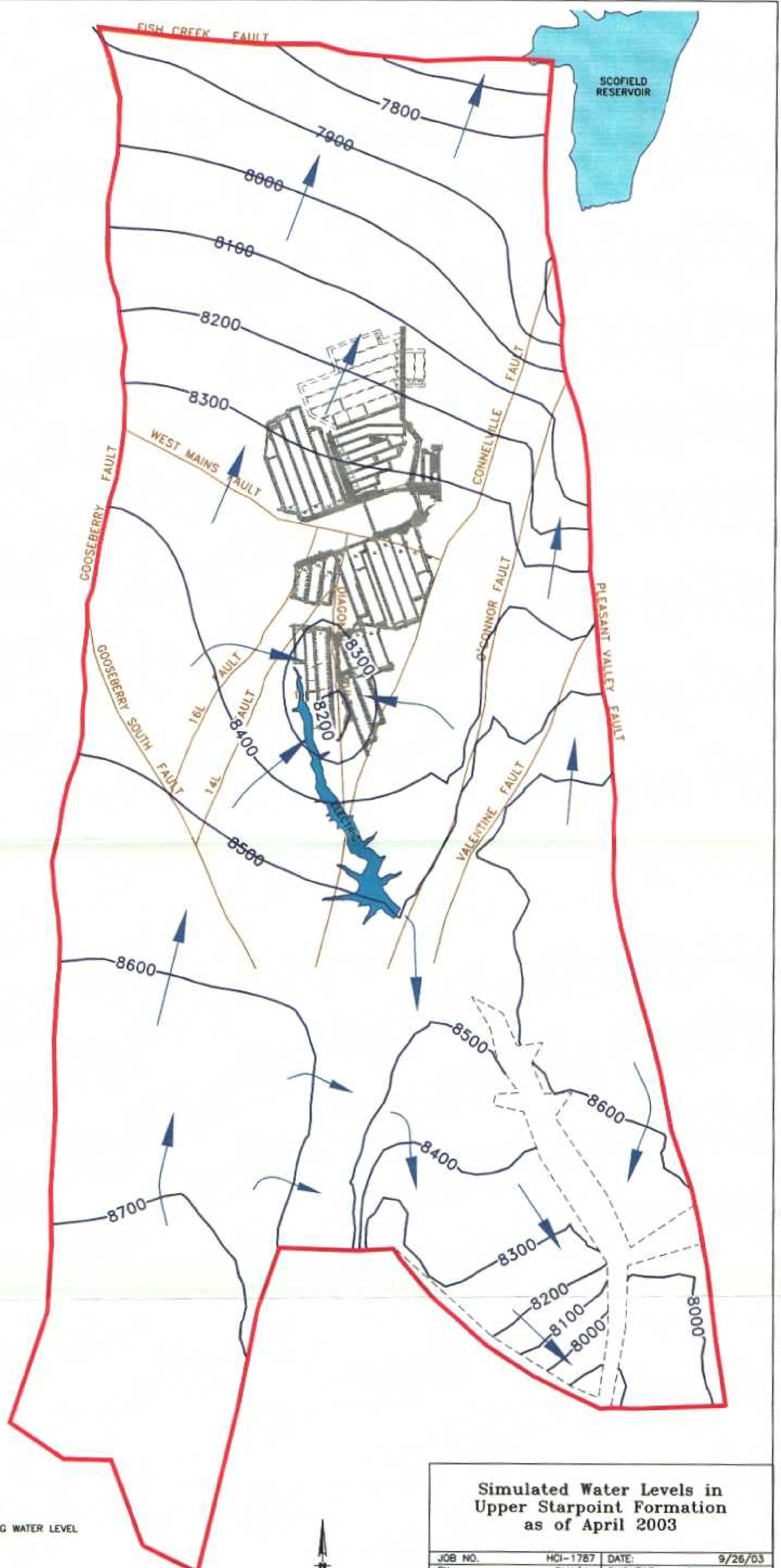


JOB NO.	HCI-1787	DATE:	9/26/03
BY:	VIU	DWG FILE:	WL-CHANGES
DRAWN:	SAC	PLOT FILE:	WL-CHANGES
CHECKED:		PLOT DATE:	9/26/03

HCI HYDROLOGIC CONSULTANTS, INC. HC|TASCA an company

Comparison of Modeled to Measured Water Level Changes in Monitoring Wells

FIGURE 18



EXPLANATION

- SIMULATED PRE-MINING WATER LEVEL CONTOUR (ft, NGVD)
- MODEL BOUNDARY
- FAULT
- AREA WHERE MANCOS SHALE IS EXPOSED AT GROUND SURFACE
- DIRECTION OF GROUND-WATER FLOW

0 — 8,000
SCALE (ft)

Simulated Water Levels in Upper Starpoint Formation as of April 2003

JOB NO.	HCI-1787	DATE:	9/26/03
BY:	RLH/VIU	DWG FILE:	SIM-WL-APR03
DRAWN:	SAC	PLOT FILE:	SIM-WL-APR03
CHECKED:		PLOT DATE:	10/2/03

HCI HYDROLOGIC CONSULTANTS, INC. — HC\|TASCA an company

FIGURE 19

EXPLANATION

- SIMULATED DRAWDOWN CONTOUR (ft, NGVD)
- MODEL BOUNDARY
- FAULT
- AREA WHERE MANCOS SHALE IS EXPOSED AT GROUND SURFACE

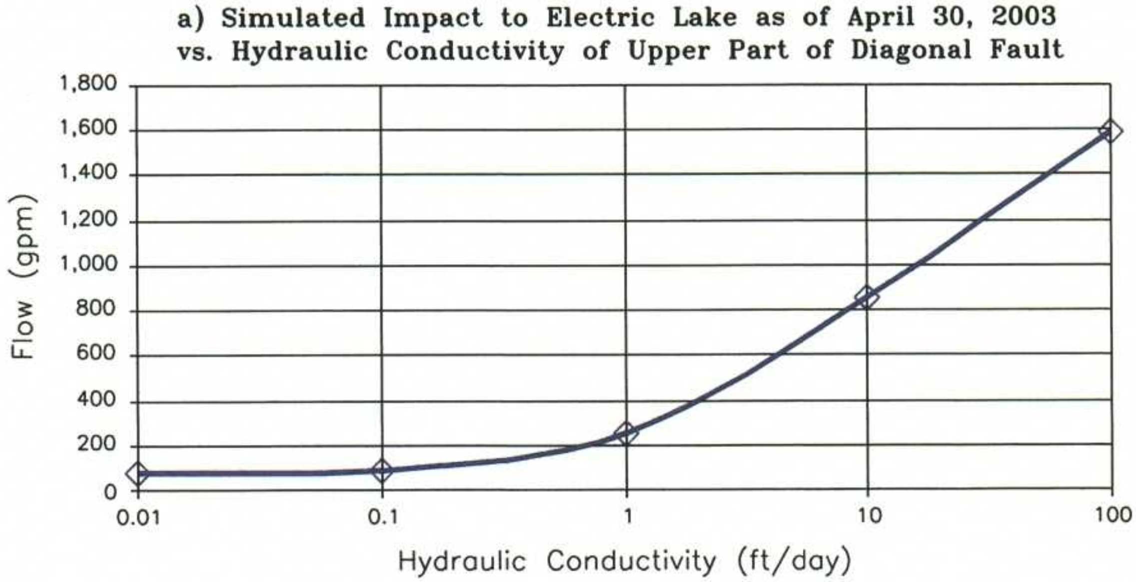
0 8,000
SCALE (ft)

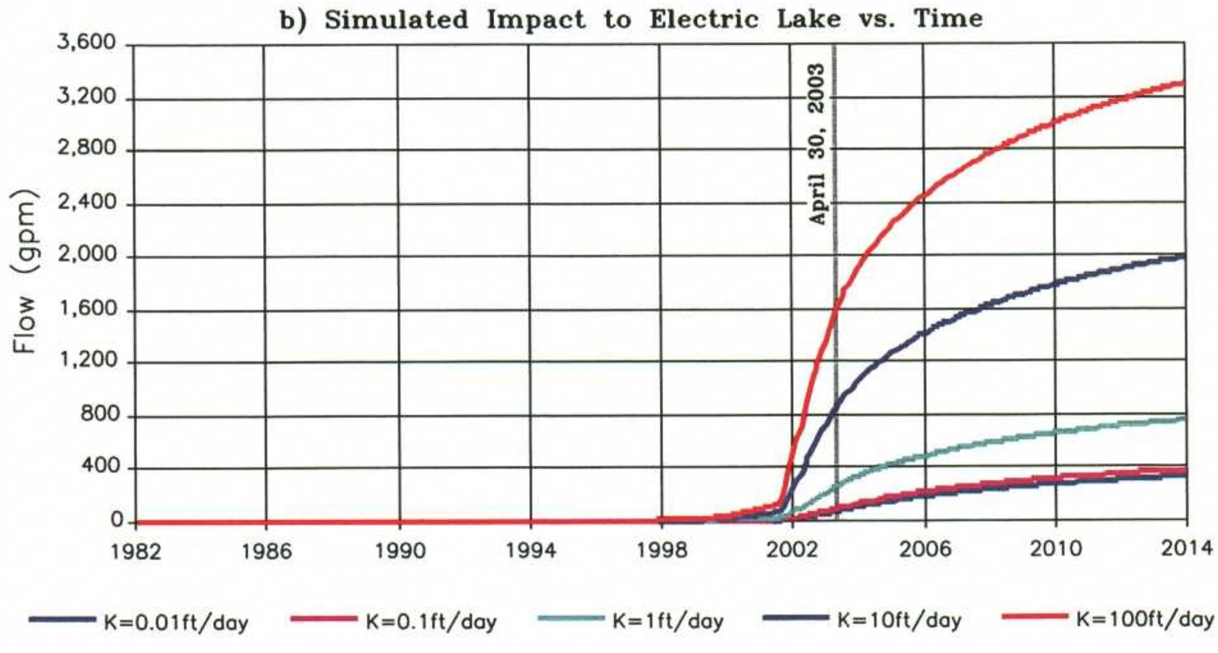
Simulated Drawdown in Upper Starpoint Formation as of April 2003

JOB NO.	HCI-1787	DATE:	9/26/03
BY:	RLH/VIU	DWG FILE:	DRAWDOWN
DRAWN:	SAC	PLOT FILE:	DRAWDOWN
CHECKED:		PLOT DATE:	10/2/03

HCI HYDROLOGIC CONSULTANTS, INC. HC|TASCA an company

FIGURE 20



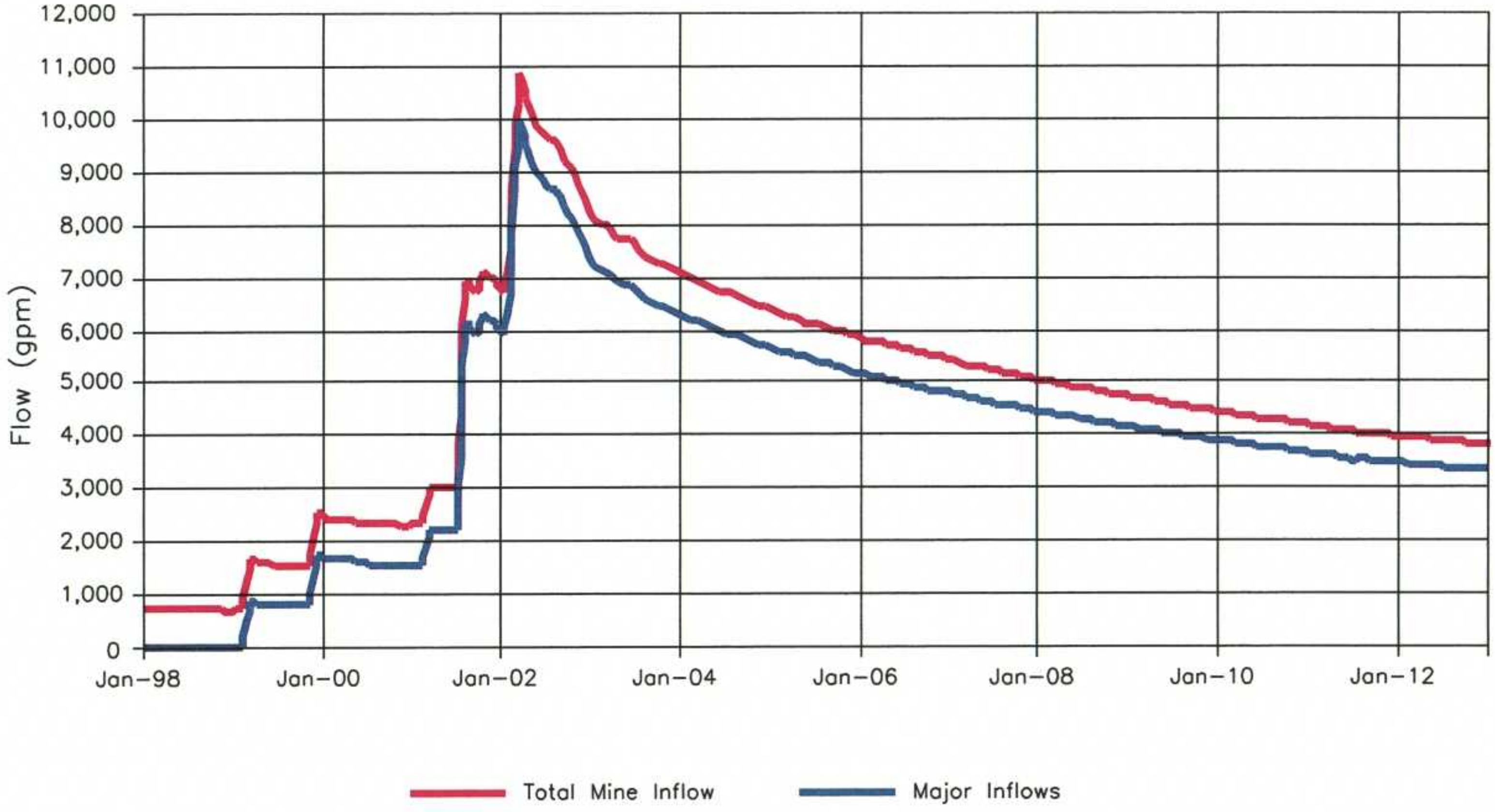


JOB NO.	HCI-1787	DATE:	9/26/03
BY:	VIU	DWG FILE:	LAKE-OUTFLOW
DRAWN:	SAC	PLOT FILE:	LAKE-OUTFLOW
CHECKED:		PLOT DATE:	9/26/03

HCI HYDROLOGIC CONSULTANTS, INC. — HC ITASCA an company

Simulated Possible Impact to Electric Lake vs. Hydraulic Conductivity of Upper Part of Diagonal Fault under Lake

FIGURE 21



HCI HYDROLOGIC CONSULTANTS, INC. HC|TASCA an company

JOB NO.	HCI-1787	DATE:	9/26/03
BY:	VIU	DWG FILE:	SIM-INFL
DRAWN:	SAC	PLOT FILE:	SIM-INFL
CHECKED:		PLOT DATE:	9/26/03

Simulated Total Ground-Water Inflow to Mine Through 2013

FIGURE 22

TABLE 1

Yield and Baseflows of Gaged Streams in Skyline Mine Area

USGS Station Number and Name	Watershed Area (ft^2)	Average October Flow (cfs)	Estimated Average Elevation (ft)	Calculated precipitation (in/yr)	Recharge[1] to Shallow Ground Water (ft/yr)
9309800 Gooseberry Creek near Fairview, UT	2.09E+08	2.29	8,825	28.73	0.35
9310000 Gooseberry Creek near Scofield, UT	4.68E+08	4.95	8,700	27.42	0.32
9310550 Pontown (Pondtown) Creek, near Scofield, UT	3.23E+08	1.17	8,425	24.53	0.11
9310600 Eccles Canyon near Scofield, UT	1.53E+08	1.80	9,000	30.57	0.37

Note:

1. Recharge to shallow ground water is assumed to be equal to discharge from shallow ground water, or stream baseflow.

TABLE 2

Monitoring Well Information

	Wells	Collar Elevation (ft, NGVD)	Screen Depth (ft < TOC)	Formation	Earliest Water Elevation		Notes
					Date	(ft, NGVD)	
Shallow	79-35-1b[1]	8,722	180?	Blackhawk	Jul-82	8576	Burnout Canyon
	79-10-1b	9,383		Blackhawk	Jul-82	8955	Upper Huntington
	79-22-2-1	9,042		Blackhawk	Aug-83	8727	Kitchen
	79-26-1	9,019		Blackhawk	Jul-83	8964	Upper James Canyon
	79-14-2a	9,052		Blackhawk	Jul-83	8980	Upper Eccles Creek
Deep	79-35-1a[1]	8,722	624	LOB	Jul-82	8572	Burnout Canyon
	98-2-1m[1]	9,271	1,251	LOB	Dec-99	8551	James Canyon
	79-14-2b	9,052	8,356	LOA	Jun-86	8460	Upper Eccles Creek
	99-28-1	9,351	1,890	Panther	Dec-99	8510	Swens Canyon
	99-21-1	9,348	1,800	Panther	Dec-99	8421	Swens Canyon
	20-28-1[1]	8,871	1,463	LOB	Nov-00	8432	Swens Canyon
	79-22-2-2	9,042	7,889	LOA/Panther	Oct-83	8596	Cascading water
	99-4-1[1]	8,842	1,302	LOB	Dec-99	8613	Boulger Canyon
	20-4-1[1]	8,874	1,560	Panther	Jan-01	8559	Boulger Canyon
	20-4-2	9,554	2,080	Storrs	Jan-01	8532	Boulger Canyon
	91-26-1	9,217	1,540-1,600	Flat Canyon/Panther	Nov-91	7937	Woods Canyon
	91-35-1	9,224	1,600-1,660	Flat Canyon	Nov-91	8034	Woods/Winter Quarters
	79-10-1a	9,383		LOA?	Jul-82	8922	broken casing?
	80-13-1	8,480	314-1,005	Starpoint	Sep-80	8360	Eccles Creek
	WQ-6	8,167	316-336	LOA/Aberdeen SS	Oct-80	8053	Winter Quarters
	WQ-8	8,121	106-126	LOA/Aberdeen SS	Nov-80	8058	Winter Quarters
	UtahFuel-7	8,080		Starpoint	recent	8045	Lower Eccles Creek
	Waste Rock	8,000		Blackhawk?	recent	7890	Lower Mud Creek
	JC-2	8,802	910-850	Storrs	Sep-01	8418	James Canyon

Note:

1. Water levels electronically monitored since Fall 2001.

TABLE 3

Timing and Volume of Ground-Water Inflows to Skyline Mine

Location	Date Inflow Began	Elevation (ft, NGVD)	Initial Inflow (gpm)	March 2003 Inflow (gpm)
14-Left Headgate	Mar-99	8,140	1,600	150
16-Left Headgate	Dec-99	7,985	1,200	150
Diagonal Fault	Mar-01	8,150	1,000	300
10-Left	Aug-01	8,040	6,500	2,800
East Submains	Oct-01	8,135	1,000	300
11-Left-x24	Feb-02	8,040	1,000	1,100
11-Left-x40	Mar-02	8,020	1,000	1,300[1]
11-Left-SU	Mar-02	8,000	1,500	1,180
Total				7,280

Note:

1. The fracture at X-Cut 40 was later exposed from X-Cut 40 to about X-Cut 34 along the longwall face; the inflow increased to a total of about 1,500 gpm.

TABLE 4

Hydraulic Properties of Hydrostratigraphic Units Simulated in Ground-Water Model

Hydrogeologic Unit		Hydraulic Conductivity (ft/day) K_h	Hydraulic Conductivity (ft/day) K_z	Specific Storage (ft^{-1})	Specific Yield ( )
Overburden[1]	upper[2]	1	1	6.0E-06	0.05
	lower	0.001	0.0004		
Upper O'Connor (UO) coal [3]		1	1		
Interburden #1[4]		0.001	0.0004		
Gob (above UO and LOB)[5]		0.01	0.004	6.0E-05	0.10
Lower O'Connor B (LOB) coal		1	1	6.0E-06	0.05
Interburden #2		0.001	0.0001		0.05
Storrs Sandstone		1	1		0.10
Interburden #3		0.001	0.0001		0.05
Panther Sandstone		1	1		0.10
Interburden #4		0.001	0.0001		0.05
Starpoint Sandstone	south area	2	0.2		0.01
	north area	0.5	0.05		0.01
Mancos Shale [6]		0.001	0.0001		0.05

Notes:

1) Includes all stratigraphic units above UO coal or LOB coal in area where UO does not exist.
2) Includes first 150 ft of weathered rock below the ground surface.
3) Has limited distribution in the model between Diagonal and Connelville faults (in mine area).
4) Located in the model below UO only.
5) Zone of subsidence-induced increase in hydraulic conductivity is assumed to extend 100 ft (about 8 times thickness of LOB) above coal and to have a hydraulic conductivity 10 times greater than lower part of overburden.
6) Located in model in area where exposed at ground surface.

TABLE 5

Hydraulic Properties of Faults Simulated in Ground-Water Model

Simulated Faults			How Simulated in Model	Hydraulic Conductivity (ft/day)		Specific Storage (ft^{1})	Specific Yield ( )
				K_h	K_z		
Large-Displacement	Gooseberry (main)		not explicitly included in model; trace defines no-flow boundary				
	Fish Creek	upper	E	1	1	6×10^{-6}	0.005
		lower		10	10		
	Pleasant Valley	upper		0.001	1		
		lower		1	1		
Intermediate-Displacement	Connelville (North)	upper		0.001	0.01		
		lower		1	1		
	Connelville (South)	upper		0.001	0.01		
		lower		0.001	0.01		
	O'Connor (North)	upper		0.001	0.01		
		lower		0.001	0.01		
	O'Connor (South)	upper		0.001	0.01		
		lower		1	1		
	Valentine	upper		0.001	0.01		
		lower		0.001	0.01		
Small-Displacement	Diagonal	upper		0.001	0.01		
		lower[1]		10	10		
	Gooseberry South	upper		0.001	0.01		
		lower		1	1		
	14-Left	upper		0.001	0.01		
		lower		1	1		
	16-Left	upper		0.001	0.01		
		lower		1	1		
	West Mains	upper		0.001	0.01		
		lower		1	1		
	10-Left		F				
	11-Left-a						
	11-Left-b						
	11-Left-c						
	East Main						

Notes:

1) $K_h = K_z$ = 100 ft/day within lower part of Diagonal Fault near pumping well JC-1
2) Upper = above LOB, Lower = below top of LOB
3) E = explicitly represented by elements with assigned hydraulic properties
4) F = simulated with *FAULT* routine of *MINEDW*

TABLE 6

Simulated Ground-Water Budgets for Pre-Mining and Current Mining Conditions

Pre-Mining Conditions			
Inflow	**(cfs)**	**Outflow**	**(cfs)**
Recharge from Precipitation	54.6	GW Boundary Outflow	0
GW Boundary Inflow	0	GW Discharge to SW	
Recharge to GW from Electric Lake	0.1	a) Mud Creek	12.5
GW Storage	0	b) Fish Creek	6.9
		c) Upper Huntington Creek/Electric Lake	10.6
		d) Huntington Creek below Electric Lake	9.5
		e) Left Fork	15.3
Total	54.7	Total	54.7
Current Mining Conditions (as of April 30, 2003)			
Inflow	**(cfs)**	**Outflow**	**(cfs)**
Recharge from Precipitation	54.6	GW Boundary Outflow	0
GW Boundary Inflow	0	GW Discharge to SW	
Recharge to GW from Electric Lake	0.2	a) Mud Creek	12.1
GW Storage	25.0	b) Fish Creek	6.8
		c) Upper Huntington Creek/Electric Lake	10.5
		d) Huntington Creek below Electric Lake	9.4
		e) Left Fork	15.2
		Subtotal	54.0
		Pumping from JC-1	8.6
		Mine Inflow	17.2
Total	79.8	Total	79.8
Calculated impact to Electric Lake = difference in recharge to GW from Electric Lake + difference in GW discharge to Upper Huntington Creek/Electric Lake			0.2

TABLE 7

Gaged and Estimated Stream Baseflows vs. Modeled Discharge to Streams

Stream Gage Location	Mean Elevation[1] of Total Drainage (ft, NGVD)	Approximate Area Modeled (ac)	Gaged Baseflow of Total Drainage (cfs)	Estimated Shallow Recharge[2] to Modeled Drainage (cfs)	Simulated Discharge to Drainage Including Springs (cfs)
Fish Creek above Reservoir	8,500	27,712	11.5	6.6	6.9
Boardinghouse Creek at mouth	9,200	1,300	1.2		1.7
Eccles Canyon near Scofield, UT	9,000	3,520	1.8		3.4
Winter Quarters Canyon	8,900	4,000		1.9	4.9
Woods Canyon	8,800	3,100		1.3	1.6
Green Canyon	8,800	1,300		0.6	0.8
Mud Creek below Winter Quarters	8,400	18,624	7.3		12.5
Mud Creek excluding Eccles, Green, Woods, and Winter Quarters	9,000	3,900		2.1	1.8
Huntington above Dam			13.0[3]		10.6
Huntington below Dam, above Left Fork	9,100	10,240		6.3	9.4
Total Huntington Drainage				19.3	20.1
Left Fork	9,200	26,000		17.5	15.3

Notes:

1. Average elevation of drainages estimated from USGS topographic maps.
2. Baseflow estimated from recharge (ft/year) based on: $R = 0.00045z - 3.66$
3. Average October-January discharge from dam, 1971 to 2002
4. Above Left Fork

Map(s) is kept with this application located in the Public Information Center of our Salt Lake City office.

PLATE I 12/03/2002

PLATE II 12/11/2002

PLATE III 10/29/2003